John Archibald Wheeler: A Study of Mentoring in Modern Physics

Chapter One: Foundation and Predicates of this Study

Section 1.1 Overview

Between 1930 and 2000, the annual production of physics doctorates in the United States increased by a factor of twelve.[1] How was such dramatic expansion possible? Most certainly, the role that physicists played in the waging of wars—both hot and cold—increased the demand for physics Ph.D.s as well as other scientists. Even before physicists became strategic assets however, the sudden and striking developments in quantum mechanics, as well as the emergence of nuclear physics, sparked a great deal of interest in mathematical and theoretical approaches to physics. In the face of this upheaval, and in order to remain attractive to students interested in the rapidly changing landscape of physics research, leading institutions went to great lengths to secure theoretical and mathematical physicists for their faculty.

But demand alone is no guarantee of supply. In order to satisfy the United States' requirement for well trained scientific and technical personnel, it was first necessary to recruit and or develop a group of master scientists

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[1] In 1930 the U.S. produced 99 Ph.D.s in physics. By 2000, the annual average was over 1200. Source: Katherine Russell Sopka, *Quantum Physics in America, 1920-1935* (New York: Arno Press, 1980), 4.65. Also cited in Peter Galison, *How Experiments End* (Chicago: University of Chicago Press, 1987), 138; American Institute of Physics, "Number of Physics Ph.D.s Conferred in the United States, 1900-2003", http://0www.aip.org.oasis.oregonstate.edu/statistics/trends/highlite/ed/figure5.htm (05 Jan 2006).

capable of training apprentices in the craft of doing science. Ironically, the European Fascism that served to exacerbate the demand for physicists during World War II initially supplied scientific craftsmen to the U.S. cadre of physicists. Many of Europe's most gifted scientists (e.g. Einstein) were Jewish, and through the implementation of anti-Semitic legislation and policies, were forced to resign their academic or research positions in Germany and elsewhere in central and Eastern Europe. Even this fortuitous influx of scientific talent was, however, insufficient to meet United States' universities increasing demand for theoretical and mathematical physicists.

For example, in the late 1930s, the Princeton physics department found itself in an increasingly expensive competition to hire at least one leading "mathematical physicist." At the time, Edward Condon (1902 – 1974) was teaching quantum mechanics at the same time he himself was learning the subject. Meanwhile, Princeton was developing a most unenviable reputation as being "somewhat backward" in regard to modern physics.[2] Consequently, in virtually every meeting of the Princeton Physics Department's Research Committee in the years 1934 – 1938, there is a discussion of to whom Princeton might offer a visiting and/or a full professorship in "Mathematical Physics." While, as is detailed below, mathematical physics is a separate enterprise from theoretical physics, the men Princeton was attempting to

[2] John Archibald Wheeler interview with Kenneth W. Ford, 20 Dec 1993—03 Jan 1994, transcript 404-405, 602.

recruit (e.g. Paul Adrien Maurice Dirac (1902 – 1984), Enrico Fermi (1901 – 1954), Werner Heisenberg (1901 – 1976), Richard Chase Tolman (1881 – 1948), John Hasbrouck van Vleck (1899 – 1980), were all known to have done significant work in theoretical physics.[3] More to the point, all had worked with graduate students who had either shown great promise, or had gone on to distinguished careers in their own right. Of course, since the supply of esteemed theoreticians and mathematical physicists was quite limited, the quest for their services quickly escalated into a bidding war that senior faculty members at Princeton despaired of losing. Consider the wording of the 21 October 1937 minutes of the physics department's Research Committee working under the supervision of department chair Henry DeWolf Smyth (1898 – 1986):

> That in view of the inability of the University to obtain with the aid of the Jones professorship a mathematical physicist of the greatest distinction and in view of the small difference in distinction of those under consideration from outside and those of our own faculty who qualify, and, further, in view of the fact that the general funds of the University appear to be inadequate to pay comparable salaries to that of the Jones professorship to our professors of mathematical physics, the Committee recommends that the donor be consulted to ascertain whether the income from the Jones Professorship of mathematical

[3] See Research Committee Minutes, 1934-1938, Box 1, Folder 12, Research Committee Minutes, 1934-1942; see also letter from H.D. Smyth to Louis A. Turner dated 22 Nov, 1937, Box 3, Folder 3, Confidential Business, 1933-1939, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

> physics my be converted into a Jones mathematical physics fund and thus administered.[4]

Meanwhile, the problem of having knowledgeable and well-regarded faculty in these burgeoning fields needed to be addressed for at least the short term. On 16 November 1937, as a stopgap measure, the Research Committee of the Department of Physics at Princeton decided to offer John Archibald Wheeler a half-year (Spring Semester 1938) position as a visiting lecturer in mathematical physics with duties to include “lecture and seminar work in nuclear theory and theoretical physics.”[5]

I would note here the Committee’s emphasis on teaching rather than on research. It is also useful to point out that the “seminar work” for which Wheeler was hired was almost certainly a graduate level course as it appears that none of the undergraduate courses offered at the time of Wheeler’s hiring were taught in a seminar format.[6]

It is also useful to note that, in comparison with other young physicists of his era, Wheeler had a very solid pedigree. He had studied under Karl Herzfeld (his dissertation advisor) at Johns Hopkins and had held post-doctoral fellowships under Gregory Breit and the legendary Niels Bohr. Then too, in less than three years at the University of North Carolina, Wheeler

[4] Committee Minutes, 21 Oct 1937, Box 1 Folder 12, Research Committee Minutes, 1934-1942, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

[5] Committee Minutes, 16 Nov 1937, Box 1, Folder 12, Research Committee Minutes, 1934-1942, Series I, Chairman H.D. Smyth Records, 1933-1953, Box 1, Folder 12, PRIN-PHY.

[6] Princeton University General Catalogue, 1937-1938, 1938-1939, PRIN.

already had supervised a Ph.D. student (Katherine Way, 1903 – 1995) who seemed to have a promising career ahead of her in nuclear physics. Later, on 16 March 1938, the Princeton physics department recommended that John Wheeler be offered a full time assistant professorship for a three year term. On 21 April 1938, the Board of Trustees formally decided to hire Wheeler.[7] The issue was not however, easily settled.

The committee that ultimately recommended the hiring of Wheeler gave strong consideration to Frederick Seitz (1911 – 2008) and it will be useful to consider the factors that went into the hiring decision. Unfortunately, we have no documentation of the committee's deliberations. Also, although department chair Henry DeWolf Smyth wrote a warm letter of condolence to Seitz after Wheeler had been chosen, the Smyth letter does not articulate the reasoning behind the Research Committee's decision.[8] We can however make some informed inferences.

As it turns out, Seitz, of General Electric's Research Laboratory in Schenectady, NY, was the first choice of Smyth. Certainly at first blush, Seitz

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[7] Exchange of letters between Wheeler (22 Mar 1938) and Smyth (29 Mar 1938), Box 6, Folder 1, Departmental Business (R-Z) 1937-1938; "Departmental recommendation to the President of the University", 16 Mar 1938, Box 3, Folder 3, Confidential Business 1933-1939; "Excerpt from Report of the Committee on the Curriculum to the Board of Trustees", 21 Apr 1938, Box 3 Folder 3, Confidential Business 1933-1939, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

[8] Letter from H. D. Smyth to F. Seitz, 30 Mar 1938, Box 6, Folder 1, Departmental Business (R-Z) 1937-1938, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

would have seemed to have the inside track. He had earned his Ph.D. at Princeton as a student of Eugene Wigner (1902 – 1995), a man who had since left Princeton for a tenured position at the University of Wisconsin, and who Princeton was just then trying to re-recruit to its faculty. Moreover, Seitz had expressed a good deal of enthusiasm for working with Wigner upon the latter's return to Princeton.[9] There were three key differences between Seitz and Wheeler. The first was that Seitz's enthusiasm, as noted above, was contingent on Wigner's return to Princeton. Indeed, he was far less inclined to accept the Princeton offer if he was to be one of a group of two or more new and younger faculty members who were brought in at the same time.[10] Wheeler, on the other hand, and perhaps based on his experience with Bohr in Copenhagen, did not seem to be troubled by the prospect of being part of a group of junior colleagues. In terms of expertise Wheeler had a background in nuclear physics, while Seitz's background was in solid-state physics. Finally Wheeler had established himself as a teacher while Seitz had established himself in industrial research. In a 9 March 1938 letter to Wigner, Smyth discounted the weight of the two backgrounds (i.e. nuclear physics versus

[9] Letter from H. D. Smyth to E. P. Wigner, 09 Mar 1938, Box 3, Folder 3, Confidential Business 1933-1939, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

[10] Regarding Seitz's attitude toward being one of two or three junior faculty that were brought in together, see letter from H. D. Smyth to L. A. Turner, 15 Feb, 1938 and letter from H. D. Smyth to L. A. Turner, 04 Mar 1938, Box 3, Folder 3 Confidential Business, 1933-1939, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

solid state physics) in the decision to hire one or the other man. Nor did Smyth seem particularly troubled by Seitz's lack of enthusiasm for being part of a group. In fact the decision was made to hire Wigner before there was a decision to hire either Wheeler or Seitz. [11] This leaves the issue of Wheeler's teaching (in particular, his work with graduate students) versus Seitz's industrial research as the salient factor in the committee's choice to offer the position John Wheeler.

As we alluded above, Eugene Wigner had been at Princeton before. In the years 1930 – 1936, he had served as a professor of mathematical physics, but for reasons that are not entirely clear, Wigner did not return to Princeton after the 1935 – 1936 academic year. Over time, various versions of the story have appeared. In a 1981 interview with Lillian Hoddeson, Gordon Baym, and Frederick Seitz, Wigner indicated that he was not asked to return to Princeton after the 1935 – 1936 academic year. On the other hand, in their 1998 National Academy of Sciences biographical memoir of Wigner, Frederick Seitz, Erich Vogt, and Alvin Weinberg indicate that Wigner was, in fact, offered a position at Princeton, but that the sticking point was that the position offered to Wigner was untenured. As for Wigner himself, his recollection, as told to Andrew Szanton, is less nuanced than the Seitz biographical memoir. Wigner told Szanton that in 1930, he and John von Neumann were both invited to visit

[11] Letter from H. D. Smyth to E. P. Wigner, 09 Mar 1938, Box 3, Folder 3, Confidential Business, 1933-1939, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

at Princeton. They each received appointments as half-time visiting professors with the obligation to spend half the academic year in Princeton. Wigner received appointment as full-time Visiting Professor for the 1935 – 1936 academic year, but much to his surprise, he was not reappointed for the next year. In retrospect, Wigner assumed that some one or more people objected to his having the position. After hearing this unpleasant news, Wigner contacted Gregory Breit at the University of Wisconsin. The two men had met when Breit was at the Institute for Advanced Study in Princeton and they had written an article together on the spectra of chemical reactions. Upon hearing that Wigner was available, Breit persuaded Wisconsin to hire Wigner as "acting professor" in 1936, and they collaborated on some more work. Then in 1938 Princeton tried to get John Van Vleck, who had been at Wisconsin and now was at Harvard, to join the Princeton Physics Department. Van Vleck declined and recommended Wigner, whom Princeton hired in fall 1938.[12]

In terms of institutional history, as the 1937 – 1938 academic year began, despite its best efforts, Princeton University had not been successful in

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[12] NBL-AIP, Interview of Eugene Wigner by Lillian Hoddeson, Gordon Baym, and Frederick Seitz on 24 Jan 1981, www.aip.org/history/ohilist/4965.html; See also: Frederick Seitz, Erich Vogt, and Alvin Weinberg. "Eugene Paul Wigner, November 17, 1902 – January 1 1995", National Academy of Sciences: Bibliographic Memoirs, http://www.nap.edu/html/biomems/ewigner.html (19 Nov 2008), also in National Academy of Sciences, *Bibliographical Memoirs,* Vol, 74, (Washington, DC: National Academies Press, 1998): 364-388; Eugene P. Wigner with Andrew Szanton, *The Recollections of Eugene P. Wigner as told to Andrew Szanton* (New York: Plenum Press, 1992), 136, 166, 171-174, 179.

securing the services of another esteemed theoretician or mathematical physicist to improve the strength of the physics faculty in the growth areas of modern physics. Thus, despite whatever the concerns that led to Wigner's two-year relocation to the University of Wisconsin, and in spite of Smyth's distinct "lack of enthusiasm" for the idea of bringing Wigner back, Princeton offered Eugene Wigner the Jones Professorship in Mathematical Physics.[13] One factor in this decision may well have been Wigner's success with graduate students, as evidenced by Seitz. So, where does that leave us?

Like most universities, Princeton wanted very much to improve the strength of its physics department, and in choosing the personnel to bring aboard it appears that a candidate's success with students, particularly graduate students, was a significant factor in the choice of whom to hire. Ideally, these new faculty members would not only add to the corpus of theoretical physics, but by instruction, example, and inculcation, they could add to the community of theoretical physicists—in a word, mentors. In the finest tradition of the guilds, these master craftsman of science would simultaneously advance the discipline and train apprentices (who themselves would be capable of advancing the discipline) with the same efficacy that nineteenth century German chemists (e.g. Justus von Liebig) had trained their

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[13] Series I, Chairman H.D. Smyth Records, 1933-1953, regarding Smyth's lack of enthusiasm for Wigner's return, see Box 3, Folder 3, Confidential Business, 1933-1939, letter from H. D. Smyth to L. A. Turner, 15 Feb, 1938 and letter from H. D. Smyth to L. A. Turner, 04 Mar 1938, PRIN-PHY.

students in the science—and artisanal craft—of chemistry. In gauging the loftiness of this aspiration, it may be recalled that the esteemed mathematical physicist William Thomson (1824 – 1907), known later in his life as Lord Kelvin, once observed:

> The world renowned laboratory of Liebig brought together all the young chemists of the day. If I were to name the great men who studied at Giessen I should have to name almost every one of the great chemists of the present day who were young forty years ago.[14]

Clearly, it was, and is, in the best interests of universities to have strong faculties, particularly in disciplines which have captured the public's imagination. But what about the discipline itself?

And so we come to the central question that forms the rationale for this enterprise: What role do mentors play in the practice and development of science and how is that related to the role they play in the development of scientific practitioners?

To be sure, there are scientists such as Albert Einstein (1879 – 1955) who enjoyed fabulously successful careers without any indication of a mentor early in their career. Freeman Dyson (1923—), Professor Emeritus of the Institute for Advanced Study in Princeton, NJ, observes, "A mentor can be helpful, but there are far too many exceptions—one thinks of Galileo, Newton,

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[14] William Thompson, "Scientific Laboratories," *Nature* 31 (Nov 1884—Apr 1885): 409-413, 410; also quoted in Joseph Fruton, "The Liebig Group: A Reappraisal," *Proceedings of the American Philosophical Society* 132 (1988), 3. In a footnote, Fruton quotes William Thomson, "all the eminent chemists who were young in 1845 were pupils of Liebig."

or Einstein—to conclude that a mentor is essential to success in science."[15] Nobel Laureate Steven Weinberg (1933—), who saw his Princeton dissertation advisor Sam Trieman (1925 – 1999) as a collaborator rather than a mentor, concurs, "a distinguished career in physics is not dependent on an apostle-like laying on of hands" by one or more senior physicists.[16]

Dyson's observation and Weinberg's experience notwithstanding, many others believe that skillful mentoring is very important to the careers of the scientific elite.[17] Donald Kennedy, past president of Stanford University has written that mentoring is "the highest form of academic duty."[18] In his autobiography *Geons, Black Holes, and Quantum Foam: A Life in Physics,* John Wheeler states unequivocally that "a good mentor" is the most important element in the early career of a researcher. "In two postdoctoral years," Wheeler continues, "I was blessed with two wonderfully strong mentors, Gregory Breit and Niels Bohr."[19] Certainly Breit and Bohr were major factors in

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[15] Freeman Dyson, personal communication with author, 17 Jan, 2008.
[16] Steven Weinberg, personal communication with author, 13 Jun, 2008.
[17] The list of examples includes, but is by no means limited to: Harriet Zuckerman, *Scientific Elite: Nobel Laureates in the United States* (New York: The Free Press, 1977; reprint, New Brunswick, NJ: Transaction Publishing. 1996), xxi, 14-15, 96 et seq; Frederic Lawrence Holmes, *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists* (New Haven, CN: Yale University Press, 2004), xix, 27; Robert Kanigel, *Apprentice to Genius: The Making of a Scientific Dynasty* (Baltimore, MD: Johns Hopkins University Press, 1986), x, xiii.
[18] Donald Kennedy, *Academic Duty* (Cambridge, MA: Harvard University Press, 1997), 116.
[19] John Archibald Wheeler with Ken Ford, *Geons, Black Holes, and Quantum Foam: A Life in Physics* (New York: W. W. Norton, 1998), 50.

John Wheeler's leadership as a physicist and his prolific contributions to the corpus of knowledge.[20] Wheeler, in turn, became one of the most influential of mentors in theoretical physics in the United States. For his part, Weinberg also seems to agree that, more often than not, a mentor is helpful to a career:

> There are some physicists who enjoy fine careers without the intervention of a mentor. Just as there are some physicists whose careers were enhanced because they had the benefit of a mentor. I am also certain that there are physicists who would have had a much more fulfilling and productive career if they had enjoyed the benefit of a good mentor.[21]

But if mentors are that important, why don't we know more about the process? Where and how do such mentors originate? Is it nature, nurture, or simply a matter of professional competence?

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[20] Wheeler's leadership in the areas of nuclear physics, quantum physics and general relativity has been noted by several historians. See, for example Peter Galison, "Physics Between War and Peace," in *Science, Technology, and the Military*, ed., Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart (Boston: Kluwer Academic Publishers, 1988), 57-58; Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1977), 328; Helge Kragh, *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton, NJ: Princeton University Press, 1996), 369-372; Helge Kragh, *Quantum Generations: A History of Physics in the Twentieth Century* (Princeton, NJ: Princeton University Press, 1999), 207-215, 279-280, 361-365, 410, 422; Silvan S. Schweber, "Quantum Field Theory Form QED to the Standard Model," in *The Modern Physical and Mathematical Sciences,* ed. Mary Jo Nye, vol. 5 of The Cambridge History of Science Series, General eds. David C. Lindberg and Ronald L. Numbers (New York: Cambridge University Press, 2003), 382-383; Herbert F. York, *Arms and the Physicist* (Woodbury, NY: American Institute of Physics Press, 1995), 117-118; Kip S. Thorne and Wojciech H. Zurek "John Archibald Wheeler: A Few Highlights of His Contributions to Physics," in *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler* ed. Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller (Princeton, NJ: Princeton University Press, 1988), 3-13.

[21] Weinberg, personal communication with author, 13 June, 2008.

One aspiration of this dissertation is that this micro-history focus on the mentoring style of John Archibald Wheeler and the outcomes of his work will offer some illumination to these questions. Before we begin, a further refinement is necessary. To be sure, one can fill hundreds of pages with testimonials to John Wheeler without gaining any novel or significant insight. In order to produce a product of scholarly value, it is necessary to contextualize this study in two frames of reference—a stereoscopic perspective. The first frame of reference situates John Wheeler's work as a mentor within the extant literature of scientific research schools.[22] The second reference frame is the

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[22] The literature on research schools is formidable. A list of sources includes, but is not by any means limited to the following: William H. Brock, “Liebigania: Old and New Perspectives,” *History of Science* 19 (Sep 1981): 201-218; William H. Brock, *Justus von Liebig: The Chemical Gatekeeper* (New York: Cambridge University Press, 1997); Maurice Crosland, “Research Schools of Chemistry from Lavoisier to Wurtz,” *The British Journal for the History of Science* 36, no. 3 (2003): 333-361; Joseph Fruton, “The Liebig Research Group: A Reappraisal,” *Proceedings of the American Philosophical Society* 132 (1988): 1-66; Joseph Fruton, *Contrasts in Scientific Style: Research Groups in the Chemical and Biochemical Sciences* (Philadelphia: American Philosophical Society, 1990); Gerald L. Geison, “Scientific Change: Emerging Specialties and Research Schools,” *History of Science* 19 (Mar 1981): 20-40; Gerald L. Geison and Frederic L. Holmes, eds., *Research Schools: Historical Reappraisals,* Osiris, 2d ser., vol. 8 (1993); Owen Hannaway, “The German Model of Chemical Education in America: Ira Remsen at Johns Hopkins (1876-1913),” in *Ambix: The Journal of the Society for the History of Alchemy and Chemistry* 23 (1976): 145-164; Frederic Lawrence Holmes, *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists*, (New Haven, CN: Yale University Press, 2004); J. B. Morrell, “The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson,” *Ambix: The Journal of the Society for the History of Alchemy and Chemistry* 19 (Mar 1972): 1-46; Mary Jo Nye, “National Styles? French and English Chemistry in the Nineteenth and Early Twentieth Centuries,” in *Research Schools: Historical Reappraisals*, ed. Gerald L. Geison and Frederic L. Holmes, Osiris,

emerging body of literature regarding scientific pedagogy, specifically the work of MIT historian David Kaiser.[23]

Section 1.2 An Underdeveloped Area of Scholarship

In 1981, Gerald Geison suggested that since research schools have been, "the predominant concrete organizational form in science since the mid-nineteenth century," any study of scientific change that does not involve individual research schools as an analytical unit of study, "is bound to be inadequate or incomplete in some respects."[24] Geison's 1981 paper (as well as his 1993 edited volume) explicitly defined research schools as, "small groups of mature scientists pursuing a reasonably coherent program of research side-by-side with advanced students in the same institutional context

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2d ser., vol. 8 (1993), 30-49; Mary Jo Nye, "Scientific Disciplines: The Construction of Identity," Chap. 1 in *From Chemical Philosophy to Theoretical Chemistry: Dynamics of Matter and Dynamics of Disciplines, 1800-1850* (Berkeley, CA: University of California Press, 1993); Kathryn M. Olesko, *Physics as a Calling: Discipline and Practice in the Konigsberg Seminar for Physics* (Ithaca: Cornell University Press, 1991); Kathryn M. Olesko, "Tacit Knowledge and School Formation," in *Research Schools: Historical Reappraisals*, ed. Gerald L. Geison and Frederic L. Holmes, Osiris, 2d ser., vol. 8 (1993), 16-29; John W. Servos, "Research Schools and Their Histories," in *Research Schools: Historical Reappraisals*, ed. Gerald L. Geison and Frederic L. Holmes, Osiris, 2d ser., vol. 8 (1993), 1-15.

[23] David Kaiser, "Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II." *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002): 131-160; David Kaiser, Nuclear Democracy: Political Engagement, Pedagogical Reform, and Particle Physics in Postwar America," *Isis*, 93 (2002), 229-268; David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005); David Kaiser, ed. *Pedagogy and the Practice of Science* (Cambridge, MA: MIT Press, 2005).

[24] Gerald L. Geison, "Scientific Change," 37

and engaging in direct, continuous, social and intellectual interaction."[25] This definition, it seems to me, very aptly describes John Wheeler, his colleagues (especially the theoreticians) and their Ph.D. students at Princeton during the years 1938 – 1976, as well as Wheeler and his (theoretician) colleagues at Texas in the years 1976 – 1986. In any event, since Geison first promulgated his definition of research school and his argument for making them an analytical unit of study, a number scholars have sought to compare and contrast research schools by investigating their guiding philosophies, social characteristics, and productivity (i.e. output of students) across regional, disciplinary, or national boundaries.

This project augments that body of scholarship by approaching the issue from a more focused frame of reference. It is useful to recall here that early in his discussion, Geison incorporated J. B. Morrell's description of an "ideal" research school. A prominent feature of that model was the presence of a "charismatic director."[26] Yet, while scholars affirm the Morrell-Geison comment that charismatic leadership is a prerequisite for the success of a research school, the art or practice of mentoring is not discussed in any of

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[25] Gerald L. Geison, "Scientific Change,20, 23 ; Geison and Holmes, *Research Schools,* 228.
[26] Geison, "Scientific Change," 23; J. B. Morrell, "The Chemist Breeders," (Mar 1972), 36-37.

these studies.[27] Nor is there any discussion of mentoring practice or proficiency in the studies which compare and contrast leadership styles in various research schools. The absence of a mentoring discourse in the context of research schools presents itself as an underdeveloped area of scholarship which this study can address.

This project is also novel in that it addresses the discipline of theoretical physics. To be clear, some very recent and quite engaging work by David Kaiser is notable in part because it addresses pedagogy in theoretical physics. Kaiser has chosen to concentrate on "paradigms" (i.e. worldviews) and pedagogical tools (e.g. Feynman Diagrams) as his fundamental units of analysis, while this present study chooses an individual mentor as the unit of analysis. [28]

With the exception of Kaiser's work, virtually all of the research school literature has focused on experimental and observational disciplines. Much of

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[27] Pamela M. Henson, "The Comstock Research School in Evolutionary Entomology," in Geison and Holmes, *Research Schools,* 175-176; Kanigel, *Apprentice to Genius*, ix [Introduction]; David Kushner, "Sir George Darwin and a British School of Geophysics," in Geison and Holmes, *Research Schools*, 220; Alan Rocke, "Group Research in German Chemistry, 78; R. Steven Turner, "Vision Studies in Germany: Helmholtz versus Hering," in Geison and Holmes, *Research Schools*, 87, 89; Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (Cambridge: Cambridge University Press, 2003), 352; Harriet Zuckerman, *Scientific Elite*, 126.

[28] David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005.); David Kaiser, "Making Tools Travel: Pedagogy and the Transfer of Skills in Postwar Theoretical Physics," in *Pedagogy and the Practice of Science*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005), 41.

this scholarship deals with artisanal competencies that were passed along (some tacitly, some explicitly) from master to apprentice. The same can be said of those studies which explicitly target mentoring in science, with three notable exceptions.[29]

In a 2001 study focusing on Niels Bohr and Richard Feynman, I examined the impact of a mentor's world-view (specifically the degree to which the mentor's approach was interdisciplinary) on the relative success of that mentor. The 2001 study did not however, address the art and practice of mentoring.[30] In the 2006 Master’s Thesis, I focused the study of mentoring to a specific setting and in a theoretical context in an effort to augment the efforts of earlier scholars in the study of research schools and scientific change.[31] One outcome of that study was that it appeared to confirm Michael Polanyi’s finding that certain elements of pedagogical style (particularly those elements that are tacitly communicated) may act as genealogical markers through

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[29] The three exceptions are Harriet Zuckerman, *Scientific Elite,* Terry M. Christensen, “Creating Chains of Wisdom: The Role of Interdisciplinarity in Mentoring” (Master's Thesis, Marylhurst University, 2001) and Terry M. Christensen, “Theoretical Physics Takes Root in America: John Archibald Wheeler as Student and Mentor” (Master’s Thesis. Oregon State University, 2006). While Zuckerman discusses aspects of mentoring, her emphasis is on the sociological contexts which foster Nobel laureates rather than the practice of mentoring.

[30] Christensen, “Creating Chains of Wisdom.”

[31] Christensen, “Theoretical Physics Takes Root.”

intellectual generations.[32] Still, the findings were qualitative and suggestive rather than quantitative and conclusive. In the present project, I will provide a quantitative foundation for assessing the efficacy of mentors in theoretical sciences in general and that of John Archibald Wheeler in particular.

Finally there is this: In David Kaiser's edited volume *Pedagogy and the Practice of Science,* Kaiser and chapter co-author Andrew Warwick close with a number of suggestions for further inquiry. This passage concludes as follows:

> Perhaps the single most important theme running through these questions is what might be learned from comparative studies. By comparing the skills and competencies generated through different training regimes we can illuminate those technical skills and sensibilities which, although normally tacit, lie at the very heart of different forms of scientific knowledge. These skills and sensibilities must be taught, learned, and applied; pedagogy is the link connecting these steps through time and space.[33]

In this study I explicitly categorize mentors as instruments of scientific pedagogy, and with a focus on the mentoring work of John Archibald Wheeler, I have developed a quantitative basis for the comparative study of mentoring

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[32] Michael Polanyi, *The Tacit Dimension* (New York: Doubleday, 1966), 21-23; Kaiser, *Pedagogy and the Practice of Science*, (2005), 2, 7 ["Introduction"] and also 66-67 [Kaiser, "Making Tools Travel: Pedagogy and the Transfer of Skills in Postwar Theoretical Physics"]; Also in *Pedagogy and the Practice of Science,* see Hugh Gusterson, "A Pedagogy of Diminishing Returns: Scientific Involutions Across Three Generations of Nuclear Weapons Science," 91; and Kathryn Olesko, "The Foundations of a Canon: Kohlrausch's Practical Physics," 323, 340-341; Olesko, "Tacit Knowledge and School Formation," in *Geison and Holmes, Research Schools,* 16-17, 28; Mary Jo Nye, "National Styles?" in Geison and Holmes, *Research Schools,* 49.
[33] Andrew Warwick and David Kaiser, "Conclusion: Kuhn, Foucault, and the Power of Pedagogy", *Pedagogy and the Practice of Science*, 406.

in theoretical physics. This investigation may therefore be seen as both an augmentation of the extant research school literature and a bridge between that body of work and the recent research dealing with scientific pedagogy.

Section 1.3 Delimiting the Discipline: Theoretical Physics

Theoretical physics was first taught as a discrete subject in 'Germanic' universities during the later half nineteenth century. Late in his career, Georg Simon Ohm (1789 – 1854) became one of the first recipients of a theoretical professorship in theoretical physics. Historians Christa Jungnickel and Russell McCormmach suggest that theoretical physics began to be seen as a separate discipline after 1870 when Gustav Kirchhoff (1824 – 1887) became a professor of theoretical physics in Berlin.[34]

By 1894, the French physics community had also concluded that a more generalized reference frame was necessary for a full comprehension of physical phenomena. The esteemed historian Mary Jo Nye describes a Faculty of Sciences Council meeting at the University of Bordeaux where it was decided to request the French Educational Ministry to create a new chair of physics for Pierre Duhem (1861 – 1916), with the title of mathematical

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[34] Christa Jungnickel and Russell McCormmach, *Intellectual Mastery of Nature: Theoretical Physics From Ohm to Einstein,* 2 vols (Chicago: University of Chicago Press, 1986), xvi-xvii; see also, Silvan S. Schweber, “Theoretical Physics and the Restructuring of the Physical Sciences: 1925-1975,” in *Big Culture: Intellectual Cooperation in Large Scale Cultural and Technical Systems,* ed. Guiliana Gemelli (Bologna: Cooperativa Libraria Universitaria Editrice Bologna, 1994), 135-136.

physics. This chair in fact came to be called a chair of theoretical physics.

Note what was said in the Council:

> Physics has made great progress in recent years and developed so that the number of people charged with presenting it has greatly increased. A deep schism has been produced between what one calls, on the one hand, experimental physics---which seeks the numerical properties of bodies---and on the other hand, theoretical physics, which attempts to encompass the ensemble of phenomena in laws or mathematical formulas.[35]

In France, as in Germany and Great Britain, the necessity of a global perspective—a generalized frame of reference in which to situate physical phenomena was clear.[36]

Even with designated professorships, and the increasing incorporation of higher mathematics in the practice of physics, it was not until early in the twentieth century that physicists came to think of themselves in terms of theoretician or experimentalist.[37] Part of this cultural inertia is due to the lag in adequate mathematical training in secondary schools. Although this deficiency

[35] Mary Jo Nye, *Science in the Provinces: Scientific Communities and Provincial Leadership in France, 1860-1930* (Berkeley: University of California Press, 1986), 213.
[36] Nye, *Science in the Provinces,* 213.
[37] Jungnickel and McCormmach, *Intellectual Mastery of Nature*, 41-42; in Helmholtz' mind, a complete physicist should be able to do both mathematical physics and experimental physics; Peter Galison, *How Experiments End*, 138.

was initially prevalent on both sides of the Atlantic, it took somewhat longer to correct in the U.S. than it did in Germany.[38]

I also want to be careful here not to give the impression of conflating applied or ‘real-world’ physics with experimental physics and/or conflating abstract or ‘pure’ physics with theoretical physics. In fact, during the formative years of theoretical physics in Germany, the extraordinary professors who were responsible for theoretical instruction were often assigned to lecture on technical or applied physics as well.[39] Coincidentally, in that same time frame, elements of the scientific leadership in the United States publicly disdained applied physics (i.e. the pursuit of science solely for profit). In any event the classification criteria were not terribly clear. As the historian Daniel Kevles observes, the term ‘pure’ referred more to a scientist’s motives rather than their area of study.[40]

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[38] Jungnickel and McCormmach, *Intellectual Mastery of Nature*,, 6-7; John W. Servos, “Mathematics and the Physical Sciences in America,” in *The Scientific Enterprise in America: Readings From Isis,* ed. Ronald L. Numbers and Charles E. Rosenberg (Chicago: University of Chicago Press, 1996), 145-148, 153-159.

[39] Jungnickel and McCormmach, *Intellectual Mastery of Nature*, 55-58.

[40] Daniel J. Kevles, “The Physics, Mathematics, and Chemistry Communities: A Comparative Analysis” in *The Organization of Knowledge in Modern America, 1860-1920,* ed. Alexandra Oleson and John Voss (Baltimore, MD: Johns Hopkins University Press, 1979), 141. Among others, Kevles was doubtlessly referring to Johns Hopkins physicist Henry Augustus Rowland. See Henry Augustus Rowland, “A Plea for Pure Science” [Address as Vice-President of Section B of the American Association for the Advancement of Science, Minneapolis, MN (15 Aug 1883)], in *The Physical Papers of Henry Augustus Rowland*, Compiled by A Committee of the Faculty of Johns Hopkins University (Baltimore, MD: Johns Hopkins University Press, 1902.), 594.

I further hasten to note that nothing in this study should be construed to suggest that one of these frames of reference (e.g. theoretical physics) can claim primacy over the other. These are complementary—though not necessarily synchronized—modes of attacking problems. A breakthrough in theory (e.g. special relativity) does not necessarily suggest an imminent and/or congruent breakthrough in experimental physics.[41]

In sum, the term "theoretical" physics, as employed here indicates a somewhat broader spectrum of inquiry that employs mathematical analysis to address the general nature of a class of phenomena. Mathematical Physics is typically focused on either mathematical descriptions of a given phenomenon (as opposed to a class of phenomena) and/or the development of mathematical techniques that can be applied to describe physical phenomena. Experimental Physics employs measuring and/or detection instruments situated in a laboratory or field setting to address the specific machinations of an individual phenomenon. Put simply, Mathematical Physics and Experimental Physics are distinguished from one another by their methods, the requisite equipment and the locale in which they are employed. Theoretical Physics is distinguished from both Mathematical Physics and Experimental Physics by its generalized frame of reference.

[41] Galison, *How Experiments End*, 12.

Section 1.4 The Choice of Subject

Why choose John Wheeler? One obvious answer is his position among the “ultra-elite” of American physicists.[42] Among his many contributions to the corpus of knowledge, in 1939 John Wheeler and Niels Bohr co-authored the first paper on the generalized mechanism of nuclear fission. Beyond that seminal work, Wheeler was a key player in the production of the 'Fat Man' plutonium weapon in the Manhattan project, and later, in the development of the Hydrogen Bomb. Wheeler introduced the scattering matrix (or S-matrix) to account for all possible final quantum states of collisions between nucleons. After turning his attention to general relativity, Wheeler and his students made a number of significant contributions to cosmology and cosmogony. In fact, John Wheeler coined the term “black hole,” and developed the concepts of a “Planck Length,” a Planck-time,” “quantum foam,” and “wormholes” in space-time.[43]

Another element is Wheeler's effectiveness as a mentor. It is significant that Wheeler’s former students have organized and published five separate

[42] Harriet Zuckerman, *Scientific Elite,* 104.
[43] See Appendix A: Timeline of John Archibald Wheeler’s Life and Works.

festschrifts in celebration of his career.[44] Yet another measure of that effectiveness is output. David Goodstein, Vice Provost of Caltech, has estimated that a typical professor of physics can be expected to 'produce' fifteen doctorates in physics over the course of his or her career.[45] By contrast, John Wheeler supervised the dissertations of fifty-one Ph.D.s and co-supervised the dissertations of five others over the course of his career.[46] In other words, John Wheeler exceeded Goodstein's "average" Ph.D. production by more than three-fold.

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[44] The festschrifts include: John R. Klauder, ed., *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday* (San Francisco: W. H. Freeman, 1972); *Family Gathering: Students and collaborators of John Archibald Wheeler gather some recollections of their work with him, and of his influence on them and through them on their own students, Assembled with the best wishes as John moves on to a new career in Texas* (Princeton, NJ: n.p., 1977); Wojciech Herbert Zurek, Alwyn van der Merwe, and Warner Allen Miller, eds., *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler* (Princeton, NJ: Princeton University Press, 1988); Daniel M. Greenberger and Anton Zeilinger, eds., "Fundamental Problems in Quantum Theory: A Conference held in Honor of Professor John Archibald Wheeler." *Annals of the New York Academy of Sciences* 755 (Apr 1995), xiii-905; John D. Barrow, P. C. W. Davies, and Charles L. Harper, eds., *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity* (New York: Cambridge University Press, 2004).

[45] David L. Goodstein, "Scientific Ph.D. problems." *American Scholar* 62, no.2 (Spr 1993): 215-221, http://0-search.epnet.com.oasis.oregonstate.edu:80/login.aspx?direct=true&db=aph&an=9304060251 (05 Jan 2006), 217.

[46] This census is based on a survey of 555 Ph.D. dissertations submitted to Princeton University and 389 Ph.D. dissertations submitted to the University of Texas at Austin during John Wheeler's tenure at these institutions. This total also includes Katherine Way, who received her Ph.D. under John Wheeler's supervision at the University of North Carolina.

To be clear, mentoring is much more than dissertational obstetrics. Often the most influential professional role models are encountered as an post-doctoral fellow. Recall here Wheeler's comments about his good fortune in having both Gregory Breit and Niels Bohr as post-doctoral mentors. Then too, there are some cases in which scientists report that the person who most influenced the course of their career was a professor from their undergraduate career.[47] In other instances, even after a scientific career has been well established, a scientist may encounter an 'elder statesmen' who serves as an informal mentor within a specific (and usually novel) area of study.[48]

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[47] See, for example, *Family Gathering,* 336 [Michael Stern], 449-452 [Charles Patton], 465-469 [Larry Smarr]. These pages contain glowing tributes penned by scientists whose direct professional experience with John Wheeler was very limited. Michael Stern took undergraduate courses from Wheeler, completed his coursework for a physics Ph.D. at MIT., changed focus and became an M.D. Stern said of Wheeler, “The History of Science is the history of man's learning to see the world with new eyes... By having been your student, I have been able, in a small way, to participate in the tradition of Copernicus, Newton, Planck, and Einstein.” Charles Patton also took classes from Wheeler as an undergraduate and went on to do graduate work and earn his doctorate at SUNY, Stony Brook. And yet, despite a relatively modest amount of time working with Wheeler, Patton felt compelled to note, “I do not yet have any students, but if I can manage to offer my students but a fraction of what you have offered me, I will have served them well.” Larry Smarr was never a Princeton student. He had read Wheeler's *Geometrodynamics* as an undergraduate, corresponded with Wheeler, and as a graduate student, met with Wheeler at a number of relativity conferences. Nonetheless, he wrote to Wheeler, “It was always your unconventional approach to physics that drew me onward,” and “I am honored to be able to say thank you for all you've done.”

[48] Peter J. Frost and M. Susan Taylor, eds., *The Rhythms of Academic Life: Personal Accounts of Careers in Academia* (Thousand Oaks, CA: Sage Publications, 1996), 498.

These odd moments of conveyed inspiration and informal mentoring are problematic in that they are very difficult to document—let alone quantify. This is analogous to the problem faced by sociologist Harriet Zuckerman as she researched and wrote *Scientific Elite.* Even though there are some three-thousand awards available to scientists just in North America, the Nobel Prize remains the 'gold standard' by which all other awards are evaluated.[49] Because of the status of the Nobel Prize, data surrounding its recipients is relatively easy to find in comparison with other symbols of scientific achievement. Similarly, although dissertation supervision is hardly the only professional assignment that involves scientific mentoring, it is a fruitful avenue of research in that it has the advantage of being comparatively well-documented on an administrative level. Put simply, it is among the very few aspects of mentoring that can be measured.

Another measure of mentoring effectiveness is the output of one's students. Harriet Zuckerman, William T. Scott, J. B. Morrell, and Joseph Fruton have all commented that elite mentors turn out an extraordinary amount of work by comparison to the average scientist. Furthermore, Zuckerman, and Fruton both have observed that this trait is passed on to the

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[49] Zuckerman, *Scientific Elite,* xxx [Introduction to the Transaction Edition]; Here, Zuckerman cites the Gale directory of Awards, Honors, and Prizes; Zuckerman uses the term 'gold standard' in association with the Nobel prize on several occasions beginning on xiii [Introduction to the Transaction Edition].

mentees of the elite.[50] In the following chapters and appendices, I will show that John Wheeler and his students follow that pattern observed by Zuckerman and Fruton.

Still another factor in choosing our subject is timing. John Archibald Wheeler came of age as a physicist just as theoretical physics was becoming established—taking root—in America. As early as 1930, a substantive cadre of American theoreticians had become established. Included in this grouping were renowned physicists such as Robert Oppenheimer (1904 – 1967), Isidor Isaac Rabi (1898 – 1988), Edwin C. Kemble (1889 – 1984), Carl Eckart (1902 – 1973), John C. Slater (1900 – 1976) , Robert S. Mulliken (1896 – 1986), Gregory Breit (1899 – 1981), Edward U. Condon (1902 – 1974), Philip M. Morse (1903 – 1985), and John H. Van Vleck (1899 – 1980).[51] Among these luminaries, all but two (Rabi and Breit) were born in the United States.[52] With the exception of Oppenheimer, all received their doctorates from American Universities. Essentially these were home-grown professionals who had spent just enough time in Europe (on an international fellowship) to become fluent in quantum mechanics and/or atomic physics. With their professional ascension,

[50] Zuckerman, *Scientific Elite, 145*; William T. Scott, "Creativity in Chemistry," in Rutherford Aris, H. Ted Davis, and Roger Stuewer, eds., *Springs of Scientific Creativity: Essays on Founders of Modern Science* (Minneapolis, MN: University of Minnesota Press, 1983), 285, 298; Fruton, *Contrasts in Scientific Style*, 23, 36, 38; Morrell, "The Chemist Breeders, 27, 30.
[51] John W. Servos, "Mathematics and the Physical Sciences in America," 152.
[52] Gregory Breit's family came to America when he was a boy; I. I. Rabi's family emigrated to the United States when he was an infant.

America became the new center of theoretical physics. In 1968, John Slater recalled that, as theoretical physics took root in America, even established Europeans were coming over, “to learn as much as to instruct.”[53]

Additionally, as noted above, the rise of Fascism and its policy of ethnic oppression in Europe precipitated an influx of elite scientists—many of whom had known or worked with members of the American cohort in Europe. Among these were Enrico Fermi (1901 – 1954), Edward Teller (1908 – 2003), John von Neumann (1903 – 1957), Hans Bethe (1906 – 2005), and (of course) Albert Einstein (1879 – 1955). That combination intellectual horsepower coupled with the availability of large experimental apparatus (e.g. the cyclotrons developed by American experimental physicist Ernest O. Lawrence (1901 – 1958)) seemed to push America on the verge of supplanting Europe as the world’s epicenter of physics. Then came the war.

Military mobilization during World War II utilized physics—particularly theoretical physics—to a level beyond all precedence. Two aspects of this phenomenon are germane to our study. First of all, as a result of the Manhattan Project and the subsequent military projects associated with the Cold War (e.g. the development of a thermonuclear weapon), the physics community was awash in research funding. In essence, within two decades, John Wheeler and his colleagues saw the entire mode of doing theoretical

[53] John C. Slater, “Quantum Physics in America Between the Wars,” *Physics Today* 21 no. 1 (Jan 1968), 43; Also cited in Kevles, *The Physicists*, 221.

physics change. Secondly, the increased demand for scientific manpower placed a premium on the ability to educate—and mentor—the physicists that would keep the U.S. technologically ahead of its adversaries. Because of their ability to train physicists at the graduate level, skillful mentors (such as John Wheeler) were considered strategic assets.[54]

Specifically, this study addresses three primary questions in regard to John Wheeler. First, what were the personal and professional characteristics that contributed to his success as a mentor? Ancillary to that inquiry, how did Wheeler's personality and professional habits compare with other well-known and/or studied mentors? Second, is there any evidence that these characteristics were inculcated into Wheeler's students and/or succeeding intellectual generations? If the answer is yes, is Wheeler the origin of a 'chain of wisdom' or simply a link in a much longer chain? And finally, are any of Wheeler's mentoring practices generalizable into a broader pedagogy for graduate studies in physics? If so, what are the key elements of Wheeler's style on which to focus? These questions require us to come to a shared understanding of the role of a mentor.

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[54] David Kaiser, "Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II" *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002), 143.

Section 1.5 The Role of Mentors: Molding the Scientific Elite

First of all, let us consider first the original and generalized meaning of 'mentor' and then turn to its characterization in recent scientific literature. The word “mentor” comes to us from the Greek poet Homer in *The Odyssey*. Recall here that Odysseus was a legendary Greek hero who ruled the island of Ithaka. He also led an army into the Trojan War. Before sailing off to war, Odysseus sought the counsel of the goddess Athene. Based on that advice, he entrusted the education and training of his son Telemachos, to his friend and counselor Mentor. Occasionally, over the twenty years that Odysseus was absent from Ithaka, Athene would appear to either Odysseus or Telemachos in the form of Mentor.[55] Thus, for Telemachos, Mentor was a teacher, surrogate father, counselor, and spiritual leader. Ultimately, the proper name Mentor became the common noun mentor, which the Oxford English Dictionary defines as: a person who offers support and guidance to another; an experienced and trusted counselor or friend; a patron, a sponsor. Since 1976, mentor has also come into use as a verb. In this study, I have and will employ both the noun and verb forms of mentor. The context of the passage in question will make the meaning clear.

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[55] See Richmond Lattimore, trans., *The Odyssey of Homer* (New York: Harper & Row, 1967; Perennial Classics Edition, New York: HarperPerennial, 1991), 46 [Book II, Line 268] is the first of many examples.

Here, I need to make clear the difference between mentoring and teaching. Unfortunately, even within the mentoring literature, I have yet to locate a concise and or articulate differentiation of these separate but related enterprises.[56] As far as the literature is concerned, there is no bright red line that categorically distinguishes teaching from mentoring. That said, it is possible to contextualize mentoring in a formally structured framework. One other caution: The instructional scenarios described below are somewhat simplified. Although all educational methodologies can be located within a

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[56] There is large body of mentoring literature: Chungliang Al Huang and Jerry Lynch, *Mentoring: The Tao of Giving and Receiving Wisdom* (San Francisco: HarperSanFrancisco, 1995); Association for Women in Science, *Mentoring Means Future Scientists: A Guide for Developing Mentoring Programs Based on the AWIS Mentoring Project* (Washington, DC: Association for Women in Science, 1993); Stephanie J. Bird and Robert L. Sprague, eds. *Mentoring and the Responsible Conduct of Research*, Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 449-640; Robert Kanigel, *Apprentice to Genius: The Making of a Scientific Dynasty* (Baltimore, MD: Johns Hopkins University Press, 1986); Shalonda Kelly and John C. Schweitzer, "Mentoring Within a Graduate School Setting," *College Student Journal* 99, no. 1 (Mar 1999): 130-148; National Academy of Sciences, National Academy of Engineering, Institute of Medicine (U.S.), *Adviser, Teacher, Role Model, Friend: on Being a Mentor to Students in Science and Engineering* (Washington DC: National Academy Press, 1977), http://oasis.oregonstate.edu/search/cQ181+.A35+1999/cq+++181+a35+1999/-2,-1,0,E/l856~2152434&FF=&1,0,,1,0 (27 Feb 06); Alice G. Reinarz and Eric Robert White, eds., *Beyond Teaching to Mentoring* (San Francisco: Jossey-Bass, 2001); Gordon F. Shea, *Mentoring: How to Develop Successful Mentoring Behaviors* [Rev. Edn.] (Menlo Park, CA: Crisp Publications, 1992); Mark A. Templin, "A Locally Based Science Mentorship Program for High Achieving Students: Unearthing Issues that Influence Effective Outcomes, *School Science and Mathematics* 99, no. 4. (Apr 1999): 205-212 , EBSCOhost/Academic Search Elite/AN1877598 (15 Jan 2001); Lois J. Zachary, *The Mentor's Guide: Facilitating Effective Learning Relationships* (San Francisco: Jossey-Bass, 2000).

pedagogical continuum, very few instructors' styles can be located at one and only one place within that spectrum. Nonetheless, some aspects of teaching technique will be dominant in any particular course. Consider, for example, undergraduate lecture-based courses in university-level education. In these instances, teaching is a unilaterally didactic process: Teachers interact with the class as a whole, and with the exception of student recitation for the purpose of evaluation, the flow of information is asymmetric. A key element here is question selection. In a lecture-based format, the instructor determines which questions he or she will address to the students. By these means, the scope and content of the course is established.

Next in the spectrum of education methodology, we find seminar-based courses. In these instances, the instructor acts as a moderator for discussion of selected topics and issues. Here, while there is a bi-lateral flow of information, the instructor still interacts primarily with the class as a whole. Also, we again find that the instructor-moderator determines the investigative framework (i.e. the scope and content) of the discussion. We also find that question selection is the key element in determining this scope and content. The difference is that in lecture-based classes, the instructor determines which questions she or he will take up while in seminar-based classes the instructor uses question selection to determine which questions the *students* will

address.[57] Nonetheless, in either of these cases, the choice of questions to be addressed is in the hands of the instructor rather than the student. This hierarchy begins to relax as students get their first taste of a mentoring relationship when they begin writing research papers.

In such an enterprise, students are encouraged to formulate and refine the questions they will explore. Imbedded in this pedagogy is the art of question selection. John Wheeler, for example, was known to emphasize this very aspect of scholarship. He strongly believed that, "The right ANSWER is seldom as important as the right QUESTION."[58] Moreover, as students are guided in the methodology of research and evaluation of source material, the instructor-student relationship becomes far more individualized. This process begins in upper division undergraduate work and continues through the early part of graduate training.

By the time a student pursues a doctorate, a substantial knowledge base has been established (and verified through examination). Nearly all of the instruction that takes place is individualized.[59] In contrast with lecture-based teaching models, students at the Ph.D. level are expected to be somewhat self-reliant where the acquisition of data is concerned. Similarly, in contrast to seminar-based teaching, they are expected to somewhat

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[57] Kathryn M. Olesko, *Physics as a Calling,* 1-2.
[58] J. Peter Vajk in an email to the author (21 Sep 05). The emphasis originates with Professor Vajk.
[59] Kennedy, *Academic Duty*, 97.

autonomously formulate the questions that drive their investigation. There is also the element of time. These are long-term relationships that evolve as the work proceeds. In sum, the mentor, in contrast to other types of instructors, does not dispense data or steer discussion. Rather the role of a mentor is to instruct a student *how to think about* the information that is already in the student's possession.[60]

We may recall here that the goddess Athene instilled confidence in Telemachos so that "among people he might win a good reputation."[61] This is also true of modern mentors. Sociologist Harriet Zuckerman observes that an important aspect of scientific mentoring is the inculcation of professional standards and conduct—a process that she refers to as "socialization."[62] We will explore the socialization of scientists at length below. For now, we note that Terrence Sejnowski, who worked as a graduate student under Wheeler at Princeton before his research interests changed to the biophysics of the brain, summed up his professional socialization nicely:

> From John Wheeler, I learned that with a sufficiently good intuition it is often possible to guess the solution to a difficult problem. But of more importance, I came to realize the extent to

[60] Zuckerman, *Scientific Elite,* 122.
[61] Lattimore, *The Odyssey of Homer,* 53 [Book III Line 75].
[62] Zuckerman, *Scientific Elite,* 123. For more on professional socialization, Zuckerman cites Robert K Merton, George G. Reader and Patricia L. Kendall, eds. *The Student-Physician: Introductory Studies in the Sociology of Medical Education* (Cambridge, MA: Harvard University Press, 1957); Orville G. Brim, "Adult Socialization," *International Encyclopedia of the Social Sciences* 14: 555-562; David A. Goslin, *Handbook of Socialization Theory and Research* (Chicago: Rand-McNally, 1969).

> which science is a social enterprise; not one man, not a single group, but rather the collective effort of a community.[63]

So, where and how does one (e.g John Wheeler) become skilled at the craft of mentoring? What, in short, are the makings of a mentor?

Section 1.6 The Makings of a Mentor

As noted in the section above, a large number of publications that address the practice of mentoring have been released in the last fifteen years. Although many of these are of a general nature (or aimed largely at business leaders and educators), a few specifically address mentoring in science.[64] However, within both the general mentoring literature and that subset that addresses scientific mentoring, there are common threads of thought. In some recently published articles that deal with mentoring in science, we are told that a good mentor is a "careful listener," a reliable (i.e. available and even-tempered) communicator. An effective mentor is sensitive to minority, gender and/or cultural issues, and is compassionate in regard to family concerns. On a professional level, the competent mentor is a role model who inculcates

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[63] Terrence J. Sejnowski to John Wheeler, Princeton University, Jan 1977 (included in the Wheeler Festschrift commemorative *Family Gathering*); Sejnowski noted his change of research interests in an email to author, 17 Jul 2009.

[64] See, for example: Association for Women in Science (A.W.I.S.), *Mentoring Means Future Scientists: A Guide for Developing Mentoring Programs Based on the AWIS Mentoring Project*; Bird and Sprague, eds., *Mentoring and the Responsible Conduct of Research*; Robert Kanigel, *Apprentice to Genius*; National Academy of Sciences (N.A.S.-U.S.), *Adviser, Teacher, Role Model, Friend: on Being a Mentor to Students in Science and Engineering*).

mentees with a sense of professional ethics and assists them in building disciplinary networks.[65] While these characteristics are part of the definition that we seek, they do not capture the relative value that these attributes will have in establishing a scientific career, nor do they adequately describe the particular attributes that scientific mentors convey to their intellectual progeny.

Perhaps the most important convention that a mentor can inculcate is the need for a robust work ethic. Note the word choice. Hard work in and of itself is insufficient for a scientist aspiring to the elite levels of her or his discipline. A 'robust' work ethic can best be described as follows: “It is good to work hard. It is better to work smart. If you can work hard *and* smart, you'll always find success.”[66] Thus in studying Wheeler's biography, we should be alert for incidents that convey the synergetic value of applying intelligence to labor.[67]

[65] What follows is synthesized from, National Academy of Sciences (N.A.S.-U.S.), *Adviser, Teacher, Role Model, Friend: on Being a Mentor to Students in Science and Engineering*, 5. However similar lists can be extracted or developed from: A.W.I.S., *Mentoring Means Future Scientists*; Bird and Sprague, *Mentoring and the Responsible Conduct of Research*; Fort, *A Hand Up: Women Mentoring Women in Science*; Reinarz and White, *Beyond Teaching to Mentoring*; Zachary, *The Mentors Guide: Facilitating Effective Learning Relationships*.

[66] I am indebted to my late grandfather Thorwald Christensen for this insight.

[67] Wheeler and Ford, *Geons*, passim. In fact, Wheeler comments on the work habits of nearly every collaborator, associate, or student that is mentioned in the text. In most cases the assessment is positive and adjectives such as “conscientious,” “scrupulous,” “methodical,” “tireless,” and/or “effective” are employed.

Another quality that the best mentors pass on is intellectual rigor. In the literature we see references to keeping an "open mind" and being "non-judgmental."[68] Such intellectual rigor demands active engagement. An illustration by analogy seems apropos here.

Imagine you are in Portland, Oregon. To the east is Mount Hood, a familiar landmark with a distinctive silhouette. If the outline of that silhouette were to be drawn on a chalkboard, it is likely that every person in the room would recognize the shape as emblematic of Mount Hood *as seen from Portland*. Similarly a mirror image of the outline would be perceived as a representation of Mount Hood's outline *as seen from the east*. But would anyone in the audience recognize Mount Hood's outline from the north, or the south, or the northeast, or the southeast? Probably not—at least initially. Stated alternatively, a full comprehension of the mountain is not possible unless we circumnavigate it.

Scientific constructs, like mountains, cannot be fully comprehended unless they are examined from multiple perspectives. Simply keeping an 'open mind' is insufficient to the practice of science. Intellectual rigor requires a scientist to actively engage the issue in question from multiple reference

[68] The need for an keeping an open mind is from National Academy of Sciences (U.S.), *Adviser, Teacher, Role Model, Friend: on Being a Mentor to Students in Science and Engineering,* (27 Feb 06), 59. The desirability for being non-judgmental is expressed in Reinarz and White, *Beyond Teaching to Mentoring*, 37.

frames and skilled mentors will instill that practice in their mentees.[69] Wheeler himself states, “There are many modes of thinking about the world around us and our place in it. I like to consider all the angles from which we might gain perspective on our amazing universe and the nature of existence.”[70]

A conscientious mentor will train her or his mentee to repeatedly examine problems with “new eyes” in the hope of eradicating false or misleading presuppositions. Such erroneous assumptions can be particularly insidious. Alfred North Whitehead famously asserted that:

> There will be some fundamental assumptions which adherents of all the variant systems within the epoch unconsciously presuppose. Such assumptions appear so obvious that people do not know what they are assuming because no other way of putting things has ever occurred to them. With these assumptions a certain limited number of types of philosophic systems are possible, and this group of systems constitutes the philosophy of the epoch.[71]

Overcoming such fundamental presuppositions requires more than just 'new eyes.'

It also requires intellectual courage—the confidence to adopt a carefully constructed conceptualization despite its unconventional nature. On 31 January 1958, Niels Bohr and Abraham Pais listened to a lecture by Wolfgang Pauli concerning elementary particles. Afterward Pauli approached Bohr and

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[69] I am deeply indebted to Sr. Cecilia Ranger SNJM, Ph.D. of Marylhurst University for the Mount Hood analogy to intellectual rigor.
[70] Wheeler and Ford. *Geons,* 153.
[71] Alfred North Whitehead, *Science in the Modern World: The Lowell Lectures, 1925* (New York: The Macmillan Co, 1925; reprint, New York: The Free Press, 1967), 48.

said, “You probably think these ideas are crazy.” “I do,” Bohr replied, “but unfortunately they are not crazy enough.”[72] Like his mentor Bohr, John Wheeler was no slave to conventional thinking. One night at Princeton, he called his (then) graduate student Richard Feynman to suggest that “positrons were simply electrons moving backward in time.”[73] To be sure, this inventory of ‘what makes a mentor’ is incomplete. Nonetheless, we have a sense of the types of events we are seeking in the early years of John Wheeler and in the analysis of his later career.

Section 1.7 Method, Strategy, and Tactics.

In general terms, I have adopted a methodology that approaches mentoring from two perspectives, internal and external. The internal approach, like much of the literature that deals with mentoring, is qualitative. Here my aim is to replicate the perspective of John Wheeler’s students. How did they see him both personally and professionally? The external approach is quantitative and relies data that derives from, but is external to the mentoring relationship. Examples of these metrics include the number of students who have apprenticed under a given mentor, the publication record of those students, including the reception of those students’ work within the physics community. I will proceed to unpack these approaches.

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[72] This anecdote is reported in Abraham Pais, *Niels Bohr's Times in Physics, Philosophy, and Polity* (New York: Oxford University Press, 1991), 29. Pais was a party to the conversation.

[73] Wheeler and Ford, *Geons,*117.

The obvious starting point for an internally oriented study of John Wheeler as a mentor is *Family Gathering,* a two-volume commemoration of Wheeler's career through 1976, assembled by Georgia Witt, John Wheeler's administrative assistant in the Department of Physics at Princeton. *Family Gathering* consists of letters of appreciation (along with some career updates) from one hundred of Wheeler's former students and associates. The full title, *Family Gathering: Students and collaborators of John Archibald Wheeler gather some recollections of their work with him, and of his influence on them and through them on their own students, Assembled with the best wishes as John moves on to a new career in Texas,* reflects the deeply personal nature of this tribute. It was presented to John Wheeler by former student and co-author Charles Misner at the Eighth International Conference on General Relativity and Gravitation at the University of Waterloo in Ontario, Canada on 11 August 1977.[74] Although *Family Gathering* is but one of five separate festschrifts published in Wheeler's honor by former students, the many letters of fond remembrance provide invaluable insight into the nature of the relationships that John Wheeler maintained with students and colleagues

[74] *Family Gathering*, iii-iv. Here, it should be noted that, in its published form, the title of this book is capitalized like a sentence rather than the headline-like capitalization found in most book titles. Misner, Kip S. Thorne and John Wheeler co-authored the 1273 page opus *Gravitation* (San Francisco: W. H. Freeman, 1973). Despite its size and cost ($249.00 hardcover; 111.95 paperback), this defining text remains in print and continues to sell.

alike. Clearly, a careful examination of this resource is critical to any study of Wheeler's Princeton years.[75]

As a research tool for this project however, *Family Gathering* has significant shortcomings. One major problem is that it predates John Wheeler's tenure at the University of Texas. Consequently, while *Family Gathering* enables the researcher to surmise much about Wheeler's relationships with his Princeton colleagues and students, there is no information whatsoever regarding his students and colleagues at Texas. Another issue is that the relationship between Wheeler and a given contributor to *Family Gathering* is not always apparent. This mix of contributors includes colleagues that were not part of either the Princeton faculty or even the broader General Relativity community (e.g. Aage Bohr) as well as post-doctoral students, Ph.D. students, and undergraduates who completed either a junior or senior thesis under the supervision of Wheeler.

Another concern is that all the information submitted by Wheeler's students is, as of the time of this writing (Winter 2009) more than thirty years out of date. Many contributors have changed university and/or laboratory

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[75] See note 43. The festschrifts include: John R. Klauder, ed., *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday*, 1972; *Family Gathering*, 1977; Wojciech Herbert Zurek et al, eds., *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler*, 1988; Daniel M. Greenberger and Anton Zeilinger, eds., "Fundamental Problems in Quantum Theory: A Conference held in Honor of Professor John Archibald Wheeler." *Annals of the New York Academy of Sciences* 755, 1995; John D. Barrow et al, eds., *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*, 2004.

affiliation. Some have passed away, and there are still others whose work leaves little or no evidentiary trace (e.g. those students whose research is largely concerned with defense related topics and who therefore have an almost non-existent publication record). Moreover, each of the contributors to *Family Gathering* has had thirty years to add to his or her curriculum vitae and their ranks of academic offspring—whom former Wheeler students have dubbed intellectual “grandchildren” of Wheeler.[76] Yet another sticking point in *Family Gathering* is a consequence of the book’s structure (i.e. an assembly of letters, curricula vitae, photos of former students with family, lists of graduate students, etc). The majority of these contributions were bound as they were submitted and therefore are not paginated in relation to the remainder of the book. This circumstance, of course, makes precise documentation of quoted passages somewhat problematic. The issue is addressed here in footnotes with the abbreviation “n.p.,” for no pagination. In sum, *Family Gathering* is both necessary and insufficient for any long-term assessment of Wheeler’s influence and-or impact on the community of physics.

Finally, as any oral historian can attest, Wheeler’s former students’ memories of him are not the most reliable form of evidence. Anecdotes may

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[76] Among the first to use the term grandchildren in relation to Wheeler’s academic influence is John S. Toll, then President of State University of New York at Stony Brook. See John S. Toll to John Archibald Wheeler 23 Jun 1977 in *Family Gathering.* See also Dieter Brill to John Archibald Wheeler (n.d.) in *Family Gathering.* After the publication of *Family Gathering* the term seems to have gained popularity among Wheeler’s former students.

well have become colored by the passage of time and codified by repetition.[77] Of course this is also true of Wheeler himself. Certainly, more then mis-remembering is involved here. Even in the short term, variations in perception and perspective will spawn differing memories of the same conversation or incident. Despite these problems, I am resistant to rejecting these recollections out of hand. Whenever practicable, I have sought independent corroboration of the facts. Often, when authentication was not possible (e.g. Wheeler's memories of interaction with his parents), factual particulars were less important than the thrust of the story. On these occasions, I have tended to accept the story at face value. If however, the facts and the timing were integral to the meaningfulness of the event, and no second source was available, then my policy has been to refrain from including the episode in this narrative. Here again, as with the internal and largely anecdotal evidence I have resisted including evidence that seems compelling but lacks corroborating documentation. For example, consider the 1972 Senior Thesis

[77] The literature is vast: for a discussion on the difficulties of distinguishing memory and history see Ronald J. Grele, "Movement Without Aim: Methodological and Theoretical Problems in Oral History," in *The Oral History Reader*, ed. Robert Perks and Alistair Thomson (London: Routledge, 1998); Soraya de Chadarevian, "Using Interviews to Write the History of Science," in *The Historiography of Contemporary Science and Technology,* edited by Thomas Söderqvist. Studies in the History of Science, Technology, and Medicine, vol. 4 (Amsterdam: Harwood Academic Publishers, 1997); Frederic L. Holmes, "Historians and Contemporary Scientific Biography," in *The Pauling Symposium: A Discourse on the Art of Biography,* ed. Ramesh S. Krishnamurthy, Clifford S. Mead, Mary Jo Nye, Sean C. Goodlett, Marvin E. Kirk, Shirley A. Golden, and Lori L. Zielinski (Corvallis, OR: Special Collections, Oregon State University Libraries, 1996), 201.

of Steven J. Pickrel, "Trapped Surfaces and the Iniial Value Problem in Geometrodynamics." Given the subject area and the timeframe in which the thesis was written, it seems highly likely that John Wheeler advised this project. Pickrel's thesis however, contains no statement of acknowledgement toward a supervising or advising professor. Moreover the online database of Senior Theses at Princeton lists Pickrel's advisor as "not available."[78] Thus, I have not included Pickrel in my census of John Wheeler's advisees. Let us now examine the quantitative approach.

The external aspect of this investigation began with an effort to identify as many former Wheeler students as possible. While this undertaking was a relatively straightforward process for Wheeler's Ph.D. students at Texas, the process was somewhat more complicated for Wheeler's Princeton students. It seems that, while Princeton maintains an online database of Senior Theses (which, as we have seen above, includes a searchable advisor category), no such database for Ph.D. dissertations is extant. Thus, in order to identify John Wheeler's Princeton Ph.D. students, it was first necessary to examine the 555 dissertations that were submitted during and immediately after Wheeler's tenure there (1938 – 1978).[79] Similarly, to be certain that this dissertation did

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[78] Steven J. Pickrel, "Trapped Surfaces and the Iniial Value Problem in Geometrodynamics," Princeton University Senior Thesis, 1972; "Steven J. Pickrel," Princton University Senior Theses Full Record, http://libweb5.princeton.edu/theses/thesesid.asp?ID=79929 (27 Feb 2009).

[79] Although John Wheeler left Princeton in 1976, his influence was acknowledged by one Ph.D. student who finished in 1978 . See, Terrence J.

not replicate any omissions or advisor misidentifications in the database of Senior Theses, it was also necessary to examine the 669 Senior theses that were submitted during Wheeler's tenure as well as during the Princeton emeritus years, 1986 – 1994, when he continued to advise undergraduate projects. The complication arises from the circumstance that, during Wheeler's early years at Princeton, there was no requirement to list the dissertation committee or even the advisor of record in the front of the dissertation just as there was no such requirement for Senior Theses. Thus, in order to link a particular student to a particular advisor, I was obliged to examine the acknowledgement section of each dissertation. Fortunately, in the vast majority of cases, this content analysis revealed the advisor of record.

There were however, a number of cases, particularly when the contributions of a number of faculty members were acknowledged, and-or ambiguous language was employed, for which it was impossible to discern an individual advisor with any sense of certainty. Indeed, simply locating the acknowledgements in a dissertation was sometimes problematic. For example, in earlier dissertations **(**ca. 1940s and early 1950s) the acknowledgement of an academic advisor was often the very last sentence on the last page preceding the academic apparatuses of appendices, bibliography, etc. Unfortunately, there were also a non-trivial number of

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Sejnowski, "A Stochastic Model of Nonlinearly Interacting Neurons," Ph.D. Dissertation, Princeton University, 1978; in this dissertation, Sejnowski unambiguously identifies John Wheeler as his advisor.

exceptions to this general rule. Then too, there were a number of students who, for reasons unknown and unknowable, omitted any acknowledgement section (or sentence) whatsoever from their dissertation or thesis (e. g. Steven Pickrel). To be clear, at both Princeton and Texas, there were also cases in which Wheeler made acknowledged contributions to the theses and dissertations of students who were not his advisees of record. Therefore, in order to identify and account for those instances, I was also obliged to examine the 389 Ph.D. dissertations and 122 Master's Theses that were submitted to the physics faculty for approval and recommendation during Wheeler's years at Texas and shortly thereafter (1976 – 1990).[80]

For all the challenges associated with the content analysis of dissertation acknowledgements, this approach proved to be fruitful on a number of levels. Beyond being able to link individual students with a particular advisor, or group of advisors, there were also occasions, as I have inferred above, in which the contributions of other faculty members (i.e. faculty

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[80] Although Princeton awarded a Master's degree in physics during John Wheeler's tenure, a thesis was not required for the Master's degree. "In order to qualify for the degree of Master of Arts a candidate is required to pass the General Examination in his field of study, make application for his degree at the office of the Graduate School and pay the graduation fee. This regulation for the Master's Degree went into effect after Commencement Day, 1935." Princeton University Catalogue 1937-1938, call number P13.73 (p324), PRIN. Also, although Wheeler left Texas in 1986, he continued to work with at least two Ph.D. students. See David H. King, "Mach's Principle and Rotating Universes," Ph.D. Dissertation, University of Texas at Austin, 1990; and Benjamin Schumacher, "Communication, Correlation, and Complimentarity," Ph.D. Dissertation, University of Texas at Austin, 1990; in both cases, John Wheeler is listed as the advisor of record.

members who were not the advisor of record) were noted. This data provided a measure of the degree that individual professors involved themselves in the learning community as a whole. Likewise, although this element was more resistant to quantification, content analysis of these acknowledgements provided a sense of how students within the graduate cohort interacted with one another. This was particularly evident in experimental research.

The aim of the quantitative external approach was to develop a means by which the work of one mentor (e.g. John Wheeler) may be compared on an ‘apples to apples’ basis with that of another (e.g. Eugene Wigner), or alternatively, a group of other mentors (e.g. the physics faculty at Princeton during Wheeler’s tenure). This comparison is based on data from the career of the mentor as well as data from the mentor’s former students.

For a given mentor in question, the basis for presumed proficiency was the number of students supervised to a Ph.D. Of course, even senior professors have been known to change institutional affiliation. Therefore, it was necessary to introduce a time component into the mix. There are two choices here: I could compare the number of students supervised by a given mentor per year of service (a quantity that is nearly always fractional) or I could compare the time interval between completed Ph.D.s. (i.e. the reciprocal of the Ph.D. students per year metric). Since interval between Ph.D. students is usually not fractional, it is conceivable that this approach offers a starker contrast. Then too, it may seem aesthetically less troubling to deal with

fractional years than to deal with fractional students. The drawback is that, as some of my physicist friends and at least one editor has pointed out, using the time interval between Ph.D.s may be confused with the number of years a student works to earn a Ph.D. under a given mentor. Thus, even though the value of the number of Ph.D. students per year is nearly always fractional, it seems to be a more straightforward approach. Moreover, it is not clear that the ‘interval between students’ metric actually provides an enhanced contrast. A specific example may prove helpful here.

In the time-frame covered by this study, Eugene Wigner supervised twenty-five dissertations over the course of twenty-nine years and Arthur Wightman supervised twenty-four Ph.D. students over the course of twenty-six years. Dividing the number of Ph.D. students by the years of service, we see that Wigner supervised 0.86 Ph.D. students per year of service and Wightman supervised 0.92 students per year of service; a difference of 0.06 student per year of faculty service. If, on the other hand, we use the inverse value (i.e. years between supervised Ph.D. students), we see that Professor Wigner had an interval of 1.16 years between Ph.D. students and Professor Wightman had an interval of 1.08 years between Ph.D. students; a difference of 0.08 years. Based on a difference of 0.06 students per year versus a difference of 0.08 years per student, it does not appear that the years per student metric offers an enhanced contrast over the more clearly presentable metric of Ph.D.

students per year of service. In consideration of the foregoing, I have chosen to rank mentors based on the number of Ph.D. students per year of service.

The next step in quantifying the efficacy of mentors was to demonstrate a link between the work habits and standards of former apprentices to those of their mentors. Here, it may be useful to recall that Harriet Zuckerman has observed that among the scientific elite, professional standards of conduct are inculcated from mentor to apprentice in a process which she terms "socialization."[81] One of these standards is scientific productivity. Zuckerman has reported that mentors of the scientific elite are extraordinarily productive. Moreover, Zuckerman and others have suggested that there is a link between the productivity of the mentor and that of the former apprentice.[82] In this study, I have presented statistical evidence in the form of publication data (see Chapter 4, Tables 4.3 and 4.4) that seems to affirm the link suggested be Zuckerman.

Furthermore, I suggest that a scientific aesthetic, a sense for significant problems that are coming ripe for solution, is also inculcated in the process of socialization. To that end, I have examined the publication records of former Wheeler apprentices (as well as the former apprentices of certain of Wheeler's

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[81] See note 61, Zuckerman, *Scientific Elite,* 123.
[82] See note 49, Zuckerman, *Scientific Elite, 145*; Walter T. Scott, "Creativity in Chemistry," in Rutherford Aris, H. Ted Davis, and Roger Stuewer, eds., *Springs of Scientific Creativity: Essays on Founders of Modern Science* (Minneapolis, MN: University of Minnesota Press, 1983), 285, 298; Fruton, *Contrasts in Scientific Style*, 23, 36, 38; Morrell, "The Chemist Breeders, 27, 30.

colleagues at Princeton and Texas) with an eye to both productivity and citation count. This latter measure, the number of times a given publication is cited, is taken as a measure of the significance of the work, and therefore the significance of the problem that work addresses.

There are actually two components to this metric. One is the number of times an individual publication is citied. The second is the number of former students' whose publications that reach a given citation threshold. In the first instance we are able to identify those researchers who are capable of very significant work that is appreciated and acclaimed by their peers. In the second instance we are able to identify those mentors with the aforementioned aesthetic—the scientific "taste" that enables them to consistently spot and solve important problems in advance of their peers—and the ability to instill that scientific aesthetic into their apprentices.

This task was accomplished in three steps. Rather than look at all the publication records from the 555 students who submitted dissertations during Wheelers time at Princeton, I made a tactical decision to first identify those ten colleagues of Wheeler who had the highest rate of Ph.D. productivity (i.e. the largest number of Ph.D. students per year of service). This same process was employed to determine who, among Wheeler's Texas colleagues, had been particularly productive mentors. Once this subset of mentors was established, I merely had to plug in the names those professors' former apprentices from our initial survey of submitted dissertations, and examine the publication and

citation data for those individuals. Of course these numbers are of limited usefulness without some frame of reference by which they may be evaluated.

David Kaiser, a historian of science at MIT, has suggested adopting the classification standards of the SLAC-SPIRES database of High Energy Physics literature and employing those standards in evaluating the impact of specific works published by former students of John Wheeler as contrasted with former students of Wheeler's colleagues at Princeton and Texas.[83] As laid out in Chapter 4, extrapolating from the relatively narrow field of High-Energy Physics and, with an eye toward conservative estimates, the author has stipulated that, publications which are cited 500 times or more (classified as "renowned") make up less than 0.5% of all physics publications; papers or books cited from 250 to 499 times (classified as "famous") make up less than 2% of all publications in physics; and those cited between 100 and 249 times (classified as "very well known") constitute less than 10% of all physics publications. Lesser works (i.e. those having been cited between 50 and 99 times (classified as "well-known") and those cited between 10 and 49 times (classified as "known") were not included in this evaluation.

The optimum resource for citation data is the *Science Citation Index*. Unfortunately, until quite recently (Winter 2009), the *Science Citation Index*

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[83] Personal communication with author, 14 Jul 2008; quoted by permission. The distribution data on citations is available at: http://www.slac.stanford.edu/spires/play/citedist/. I am indebted to Professor Kaiser for his assistance with this point.

existed in three media formats: print, CD-ROM, and a web-based database, the ISI Web of Knowledge. A further complication is that these formats did not overlap in time. Unfortunately, as a visually impaired scholar, neither the print volumes nor the CD-ROM were particularly accessible to me. This leaves the ISI Web of Knowledge database. The problem here is that this resource only encompassed material published in 1970 and beyond, and given the timeline of our study (1938 – 1994) the ISI database would be of very limited usefulness.

Other accessible databases include the SLAC-SPIRES High Energy Physics database (a slightly modified version of whose classification scheme I have adopted) and Google Scholar. As it turns out, there are non-trivial problems with both resources. The SLAC-SPIRES site is, as the name suggests, focused on High Energy Physics, and therefore somewhat less comprehensive than is required for the study of multi-faceted group of physicists such as Wheeler and his students. Google Scholar, on the other hand, is so inclusive as to be redundant. For example, a Google Scholar search for publications written by “JA Wheeler” lists some 895 books and articles.[84] Given that there are only 396 entries in John Wheeler’s personal

[84] Google Scholar, search author “JA Wheeler”, http://scholar.google.com/scholar?as_q=&num=100&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JA+Wheeler%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= (23 Nov 2008).

bibliography, the Google Scholar data would also seem to be of limited usefulness.

The good news is that Google Scholar is similarly redundant for all author searches. Therefore, it is useful as relative measure or, more charitably, a first order approximation of scientific productivity as estimated by the number of articles a given scientist has published. For better or worse, Google Scholar seems to employ this same redundancy as it assesses citation counts. In the case of John Wheeler, we see that as of 23 November 2008 the opus *Gravitation* (coauthored with former students Charles Misner and Kip Thorne) has been cited 2,723 times. Further down the webpage, we find instances when it appears that a particular chapter or section of *Gravitation* has been cited by some group of articles.[85] Again, this redundancy seems to be a universal feature of Google Scholar. Therefore the data pulled from this resource represents a first-order approximation that is at least minimally suitable for our comparative study. There are however, two other caveats in order.

Caveat One is that the data cited here is time sensitive. There are two factors at play here. On the one hand, every time a paper or book cites one of the publications in the Google Scholar database (or, for that matter, the SLAC-SPIRES database), the citation count will increase by one. On the other hand, over time, as the concepts presented in a given publication become seen as

[85] Google Scholar, search author “JA Wheeler” (23 Nov 2008).

less novel, the rate of citation increase drops to very nearly zero. That said, the aforementioned *Gravitation* is still in print and even though it has not been revised in thirty-five years, it is still cited.

Caveat Two is that while our quantitative approach seems promising, it is not applicable to experimental physics. In the relatively recent past, experimental physicists have adopted the unfortunate custom of extensively shared authorship. Consider the example of Dr. Richard W. Kadel who earned his Ph.D. under the supervision of Professor Val L. Fitch, a Nobel Laureate and colleague of John Wheeler at Princeton. According to Google Scholar, as of November 2008, Dr. Kadel has some 266 publications and one of them, “Observation of Top Quark Production in p^{-} p Collisions with the Collider Detector at Fermilab”, has been cited 790 times. This citation count places the Kadel paper in the “Renowned” class. But to what extent is the paper the work of Kadell? A closer look reveals that the paper is five pages in length and has

434 authors.[86] Moreover, since the authors' names appear in alphabetical order, there is no way to infer to what extent Dr. Kadel contributed to the final product, and therefore no reliable way to surmise a link between Dr. Kadel's work habits (or, for that matter, the significance of his work) and the training he received during his apprenticeship under Professor Fitch.

In closing the discussion of methodology as it relates to databases, I am compelled to call attention to another database of interest to this study. The Mathematics Genealogy Project, which is being developed by the Department of Mathematics at North Dakota State University, is a relatively new endeavor that aims to document the intellectual lineage of leading mathematicians. For example, after entering John Wheeler in the search engine, we can see that one of his students, Arthur Wightman completed his Ph.D. from Princeton in 1949 with a dissertation titled, "The Moderation and Absorption of Negative Pions in Hydrogen." As of November 2008, the North

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[86] See Google Scholar, search author "RW Kadel", http://scholar.google.com/scholar?as_q=&num=10&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22RW+Kadel%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= ; See also, R. W. Kadel et al [433 others], "Observation of Top Quark Production in p^{-} p Collisions with the Collider Detector at Fermilab", *Physical Review Letters* 74, No. 14 (3 Apr 1995), 2626-2631, http://prola.aps.org/abstract/PRL/v74/i14/p2626_1 (23 Nov 2008); See also R. W. Kadel et al [627 others], "Observation of CP Violation in the B^0 Meson System" *Physical Review Letters* 87, No. 9 (27 Aug 2001), 091801-1 [8 pages], http://prola.aps.org/abstract/PRL/v87/i9/e091801 (23 Nov 2008); See also R. W. Kadel et al [405 others], "Measurement of the W Boson Mass", *Physical Review D* 52, No. 9 (01 Nov 1995), 4784-4827, http://prola.aps.org/abstract/PRD/v52/i9/p4784_1 (23 Nov 2008).

Dakota database lists Wightman as having some twenty-one doctoral students and some 368 "descendants."[87]

Unfortunately, there are significant omissions in this database. In the case of John Wheeler, for example, only twelve of Wheeler's Ph.D. students are listed. Wheeler is however, credited with 507 'descendants' or intellectual grandchildren.[88] The surprising omission of nearly forty of Wheeler's students may be due, at least in part, to the focus on mathematics. Still, it is hard to imagine that eighty percent of Wheeler's students lacked a sufficient mathematical pedigree to be included here.

Then too, there is the case of Frederick J. Ernst. Typically, the Mathematics Genealogy Project lists only the Ph.D. students that can be traced in a given intellectual lineage. Along with these students names are the institutions from which they received their Ph.D. and the year in which their doctorate was awarded. The Ernst listing is atypical because there is neither an institution nor a degree year listed.[89] As it turns out, Frederick Ernst submitted a Senior Thesis at Princeton in 1955 that was supervised by John

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[87] North Dakota State University, The Department of Mathematics, "The Mathematics Genealogy Project", http://genealogy.math.ndsu.nodak.edu/id.php?id=11904 (23 Nov 2008). One of Wightman's students is the renown historian of science, S. Silvan Schweber.

[88] On the Mathematics Genealogy database, the search terms "John Archibald Wheeler", "John A. Wheeler", and "J. A. Wheeler" yield no matches. "John Wheeler" only came up when I sought a listing for Wheeler's former student, Arthur Wightman.

[89] Mathematics Genealogy Project (23 Nov 2008).

Wheeler (see Appendix E, p. 698). Ernst's graduate work, however, was completed at the University of Wisconsin in 1958 without any apparent involvement on Wheeler's part.[90] In sum, while this venture shows promise, as November 2008, it remains a work in progress. Nonetheless, a project that focuses on intellectual lineage is an indication that this study should enjoy some resonance with the mathematics and physics communities.

Section 1.8 Review

This thesis addresses mentoring in theoretical studies, a heretofore underdeveloped area scholarship. One object is to illuminate the art and practice of mentoring, in both a qualitative and quantitative sense as it is situated in a research school setting. A second, and related objective is to bridge the gap between the extant studies of research schools and the more recent examinations of pedagogy in scientific training. Because of his evident skill as a mentor and his position on the timeline of theoretical physics in America, John Archibald Wheeler is thought to be a particularly well-suited focus for this investigation. Finally, while the study faces a number of evidentiary challenges, there is also the promise significant insights into the production of science.

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[90] Frederick Joseph Ernst, Jr., "The Wave Functional Description of Elementary Particles with Application to Nucleon Structure" (Ph.D. diss., University of Wisconsin, 1958).

In the following chapter, I will further establish the foundation of this investigation by presenting a biographical sketch of Wheeler, paying particular attention to those events and circumstances that appear to bear on his career as a mentor.

Chapter Two: The Nature and Nurture of a Mentor: John Archibald Wheeler as Student

Section 2.1 Overview

John Archibald Wheeler's success as a mentor can be traced to a number of factors—some of which are biographical (as opposed to professional) in origin. That said, a systematic approach to the issue necessarily includes the obvious (i.e. Wheeler's eminence in theoretical physics). As noted in Chapter 1, John Archibald Wheeler was one of the United States' most celebrated physicists and among the few to make significant contributions in both quantum physics and general relativity. In her study of the scientific elite and Nobel laureates in the United States, social historian Harriet Zuckerman refers to Wheeler as a member of the “ultra-elite” among scientists.[91]

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[91] Harriet Zuckerman, *Scientific Elite: Nobel Laureates in the United States* (New York: The Free Press, 1977; reprint, New Brunswick, NJ: Transaction Publishing, 1996), 104. See also, Kip S. Thorne, and Wojciech H. Zureck “John Archibald Wheeler: A Few Highlights of His Contributions to Physics,” in *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler,* ed. Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller (Princeton, NJ: Princeton University Press. 1988): 3-13.

However, professional virtuosity and intellectual lineage do not by any means guarantee excellence as a mentor.[92] Einstein was, of course, famous for not having any students. The late Richard Feynman, a Nobel laureate (and former Wheeler Ph.D. student) is another case in point. Despite wide acclaim for his ability to present concepts with clarity and verve, Feynman was not a prolific mentor. Over a career that spanned four years at Cornell and thirty-five years at Caltech, Feynman had at most a handful of Ph.D. students.[93] Another Nobelist, P. A. M. Dirac, was also notoriously reluctant to take on graduate students. Over his career, Dirac officially supervised a total of seven Ph.D.

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[92] Zuckerman, *Scientific Elite*, 101-103, 105, 109, 150; See also Robert Kanigel, *Apprentice to Genius: The Making of a Scientific Dynasty*, (Baltimore, MD: Johns Hopkins University Press, 1986), 234-235; J. B. Morrell, “The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson,” *Ambix: The Journal of the Society for the History of Alchemy and Chemistry* 19 (Mar 1972), 19; William Thomson, “Scientific Laboratories,” *Nature* 31 (Nov 1884—Apr 1885): 409-413, see 410 where Thomson writes, “The world renowned laboratory of Liebig brought together all the young chemists of the day. If I were to name the great men who studied at Giessen I should have to name almost every one of the great chemists of the present day who were young forty years ago.”; Also quoted in Joseph Fruton, “The Liebig Group: A Reappraisal,” *Proceedings of the American Philosophical Society* 132 (1988), 3. In a footnote, Fruton quotes William Thomson, “all the eminent chemists who were young in 1845 were pupils of Liebig.”

[93]Feynman's skill as a classroom and/or public lecturer was well known. Moreover, his text *The Feynman Lectures on Physics* is considered a must for any physicist's library (In this regard see James Gleick *Genius: The Life and Science of Richard Feynman* (New York: Vintage Books, 1992), 363-364). For more on Feynman as a mentor see Terry M. Christensen, “Creating Chains of Wisdom: The Role of Interdisciplinarity in Mentoring,” Master's Thesis, Marylhurst University, 2001. The number of Feynman Ph.D. students is addressed on p.3 and pp. 59-61.

students.[94] Clearly, talent in and of itself is no guarantee of productivity in mentoring. So what does matter?

By way of understanding the factors that contributed to Wheeler's development of a personal style and method for mentoring, this chapter will present a chronological adumbration of the first twenty-four years of John Wheeler's life. These years include his childhood and early education, followed by his experience studying and doing physics with Karl Herzfeld, Gregory Breit, and Niels Bohr. This chapter also contains a section which addresses John Wheeler's enigmatic relationship with Albert Einstein. What follows is a selective analysis of these years with a view to thinking about the character of mentors and mentorship, as discussed in Chapter 1.

Section 2.2 Nature and Nurture: The Young Wheeler

Like most accounts of the life of an unusually gifted and influential physicist, the sources for John Wheeler's life depict an exceptional young man.[95] Many of the standard stories and themes associated with biographical

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[94] R. H. Dalitz and Rudolf Peierls, "Paul Adrien Maurice Dirac: 8 August 1902—20 October 1984," *Biographical Memoirs of Fellows of the Royal Society* 32 (1986), 154-156. Dirac also had some mentees for whom he was not the dissertation supervisor of record. Notable among these were Dennis Sciama and Subrahmanyan Chandrasekhar.

[95] As yet, a scholarly biography of John Wheeler does not exist. The primary sources for learning about his youth are: , "Wheeler, John Archibald, 1911-2008 ," interview by Kenneth W. Ford (transcript), Princeton, NJ and Meadow Lakes, NJ, 06 Dec 1993—18 May 1995, NBL-AIP, Call number [OH5]John Archibald Wheeler and Kenneth Ford, *Geons, Black Holes, and Quantum Foam: A Life in Physics* (New York: W. W. Norton, 1998); John Archibald

studies of scientists in their youth are present in Wheeler's life story. Though there is some evidence that the nature of these stories varies with discipline, the stories of Wheeler's youth resonate with those of other American physicists (e.g. Richard P. Feynman (1918 – 1988)).[96] That said, these elements are nonetheless important to the narrative. Among the themes to explore in the context of this study on mentorship are influences from family, friends, and teachers. Other areas of interest include the young Wheeler's attitudes toward education as well as his style of thinking and working. Finally, this chapter also examines the interactions of the young Wheeler with three remarkable and effective teachers and mentors in physics: Karl Herzfeld, Gregory Breit, and Niels Bohr.

John Archibald Wheeler, the oldest of four children, was born on the ninth of July, 1911 in Jacksonville, Florida. Wheeler's parents, Joseph Lewis Wheeler and Mabel Archibald Wheeler, were both librarians. Although Mabel

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Wheeler, "Wheeler, John Archibald, 1911-2008 ," interview by Charles Weiner and Gloria Lubkin (transcript), Princeton, NJ, 05 April 1967, NBL-AIP, Call number [OH537]; Jeremy Bernstein, *Quantum Profiles* (Princeton, NJ: Princeton University Press, 1991).

[96] For the variation of childhood stories among disciplines see Ronald E. Doel, "Oral History of American Science: A Forty Year Review," *History of Science* 41, no. 4 (Dec 2003): 349-378, 360-361, available online: <http://oasis.oregonstate.edu/search/tHistory+of+Science/thistory+of+science/1%2C2%2C2%2CE/c8561053566&FF=thistory+of+science&1%2C1%2C%2C1%2C0> (24 June 2006). See also Richard P. Feynman and Ralph Leighton, *Surely You're Joking Mr. Feynman: Adventures of a Curious Character* (New York: W. W. Norton & Co, 1985), 16-21, Feynman too, was fascinated by gadgets during his youth and achieved neighborhood acclaim for fixing radios by "thinking."

Wheeler left her career in order to raise her children and manage the Wheeler household, she remained active in library affairs by helping her husband evaluate books for library purchase. As they became old enough to participate, the Wheeler children joined in these discussions. As one might expect, the Wheeler household was filled with books. In addition to the typical childhood favorites *Swiss Family Robinson* and *Robinson Crusoe,* Wheeler reports that, early on, he had an appetite for technical books. Included in these were Franklin Day Jones' *Mechanisms and Mechanical Movements* (1920) and J. Arthur Thomson's *Introduction to Science* (1911).[97]

In his autobiography, John Wheeler notes that, although his mother seemed very happy in marriage, throughout her life she was "sensitive about not having a college degree." Perhaps because of that perceived shortcoming, Mabel Wheeler "made sure that all her children were encouraged in their academic pursuits." Wheeler continues:

> As the firstborn son, with an inclination toward mathematics and science, I got a disproportionate share of my mother's attention. My brothers and sister felt this imbalance. I didn't feel smothered, but I was aware of the expectations that she held for me.[98]

In addition to the foregoing, the Wheeler autobiography contains a number of anecdotes that underscore a family life that emphasized the importance of

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[97] Wheeler interview with Weiner and Lubkin, 05 April 1967; Wheeler and Ford, *Geons,* 82; See also Franklin Day Jones, *Mechanisms and Mechanical Movements* (New York: Industrial Press, 1920); J. Arthur Thompson, *Introduction to Science* (New York: H. Holt & Co., 1911).

[98] Wheeler and Ford, *Geons,* 65-66.

learning.[99] Of course, a child is also influenced by adults, teachers in particular, who are outside the family circle.

In John Wheeler's case, numerous family relocations complicate the issue of identifying influences outside the family. Although the point is not emphasized in the Wheeler autobiography, John Wheeler's father, Joseph Wheeler, was no ordinary librarian. Over the course of his career he wrote several books on the topics of library management and the place of the public library in American communities. Wheeler said of his father, “He saw the public library as the university of the people.”[100] In fact, Joseph Wheeler was chosen to manage exhibits for the American Library Association at the (1915) San Francisco and (1926) Philadelphia World's Fairs.[101]

In order to advance in his profession, the elder Wheeler accepted positions at a series of libraries. For example, in September 1912 (after only eighteen months in Florida), Joseph Wheeler took a position as assistant director of the Los Angeles Public Library. Shortly thereafter, the Wheeler family moved from Jacksonville to Glendale, California. In 1916, after he completed the San Francisco assignment for the American Library

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[99] Wheeler interview with Ford, 06—20 Dec 1993, Transcript 101-309.
[100] Wheeler interview with Weiner and Lubkin, 05 April 1967, 2.
[101] Wheeler and Ford, *Geons,* 67; In fact, the elder Wheeler's papers are presently housed in the Joseph Wheeler Collection at the College of Information of Florida State University. In a 20 Mar 2006 email to the author, Pamela J. Doffek (Librarian, Goldstein Library, College of Information, Florida State University) confirms that the papers of Joseph Wheeler are in the University's collection. As of this writing (2008) the collection remains unprocessed.

Association, Joseph Wheeler became head librarian of the Youngstown, Ohio public library. However, his stay in Youngstown was intermittent. During the war years (1917 – 1918), Wheeler's father worked for the Libraries War Service and was responsible for all book selections sent to overseas Armed Forces Libraries.

Another of the moves was the result of Joseph Wheeler’s 1912 bout with scarlet fever, which left him with a weak heart. In 1921, in order to build up his health, the elder Wheeler took a sabbatical from the Youngstown library and relocated, with his wife and children to a farm owned by the Wheeler family near Benson, Vermont. Then, in October of 1922, Joseph Wheeler and his family returned to Youngstown. Later, after working for the American Library Association at the Philadelphia World's Fair in 1926, Joseph Wheeler was hired as the director of the Enoch Pratt Free Library in Baltimore.[102]

Consequently, John Wheeler's early education began in Washington, DC and continued (sequentially) in Youngstown, Ohio, in Benson, Vermont, back in Youngstown again, and concluded in Baltimore. Under these circumstances (i.e. repeatedly having to adjust to a new school), one might presume that Wheeler's public school experience was something less than optimal. In fact the moves—particularly the move to Vermont—advanced rather than hindered Wheeler's educational progress. More to the larger point,

[102] Wheeler and Ford, *Geons,* 67, 71-73, 83.

the family did not remain in a community long enough for Wheeler to establish meaningful relationships with any non-family adults other than teachers.

Two such teachers are prominently mentioned in *Geons.* The first is Mary Donovan who taught between twenty-five and thirty-five pupils (spanning eight grades) in a one room schoolhouse near Benson, Vermont.[103] After completing the first grade in Washington, DC, Wheeler completed the second and third grades in Youngstown. He was finishing his fourth grade year when the family moved to Vermont. There, in Mary Donovan's classroom, Wheeler made remarkable progress. In *Geons,* he remarks:

> I don't remember being considered especially precocious, and I don't remember getting any special attention from Mary Donovan, but somehow, after a little more than one school year in Vermont, I moved into the eighth grade back in Youngstown, four grades beyond the one I had left. Part of the reason, I think, is that I could listen in on the teacher's instruction of the older children and quietly work along with them. Also, I had time during the day to move at my own pace through the available books, and I did as much mathematics as I could. Since the first grade, when my grandfather Archibald had introduced me to mathematics, I had loved it and found that it came naturally to me.[104]

Mary Donovan's influence is more apparent later in Wheeler's career when

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[103] Wheeler interview with Weiner and Lubkin, 05 April 1967, 5. Here Wheeler recalls twenty-five students in Mary Donovan's school. In *Geons,* (p80) Wheeler remembers the number of students as thirty-five.

[104] Wheeler interview with Ford, 06 Dec 1993, 207; See also, Wheeler and Ford, *Geons,* 80.

Wheeler became known for giving his students “barely enough advice to keep [them] from floundering and but never so much that [they] felt that he had solved the problem for them.”[105]

Although Mary Donovan did not openly extol Wheeler's academic ability, once Wheeler was back in Ohio, a number of his teachers took a more proactive role in his development. Most prominent among these was Wheeler's mathematics teacher, Lida F. Baldwin. “She gave me extra work, extra reading, and extra encouragement,” recalls Wheeler. Nor did Baldwin’s commitment to Wheeler's academic success stop at the schoolhouse door. One afternoon, according to Wheeler, she called on his father at the Youngstown Library, “to make sure, I suspect, that my parent's commitment to my education matched her own.”[106] Wheeler also mentions Professor [Francis] Murnaghan (1893 – 1976) who taught calculus at Johns Hopkins.[107] Murnaghan was, other than Karl Herzfeld (Wheeler's dissertation advisor), “The best teacher I ever had as far as exposition [and clarity are]

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[105] Kip S. Thorne, *Black Holes and Time Warps: Einstein's Outrageous Legacy* (New York: W. W. Norton & Co., 1994), 262.
[106] Wheeler and Ford, *Geons,* 80-81; Wheeler interview with Weiner and Lubkin (05 April 1967), 3.
[107] J. J. O'Connor and E. F. Robertson, “Francis Dominic Murnaghan.” MacTutor History of Mathematics (October 2003), Available Online: <http://www-history.mcs.st-andrews.ac.uk/Biographies/Murnaghan.html> (21 Mar 2006); North Dakota State University, Department of Mathematics, “Francis Dominc Murnaghan,” The Mathematics Genealogy Project [Online], Available:<http://www.genealogy.math.ndsu.nodak.edu/html/id.phtml?id=11540> (21 Mar 2006).

concerned."[108] Coming from Wheeler, a man famous for his word-smithery, that is quite an endorsement.

Clearly, Wheeler's childhood was one in which he was inculcated with the importance of education. Desire alone however is insufficient to achieve academic goals. The pursuit of knowledge—particularly at the highest levels—takes tenacity and a great deal of work. An elite mentor must possess these qualities and, be able to inculcate that same robust work ethic in her or his mentees. So, where are the roots of John Wheeler's work ethic?

John Wheeler seems to have developed a tacit understanding of the importance of industriousness largely through the example of his parents. In Wheeler's autobiography, there is little evidence that the inherent worth of work was a frequent discussion topic. He recalls that, "It was an era when children's character and intellect were supposed to be developed through discipline and hard work, not through rewards and flattery."[109] As he got older, Wheeler became responsible for certain family chores such as mowing the lawn and gathering eggs (after returning to Youngstown from Vermont, the Wheelers kept chickens in their back yard). Additionally, in both Youngstown and Baltimore, Wheeler had a paper delivery route. Even so, as a typical teen, particularly as college approached, John Wheeler was not above attempting to avoid jobs that he found tedious or unduly taxing. From time to time, he would

[108] Wheeler interview with Weiner and Lubkin (05 April 1967), 6.
[109] Wheeler and Ford, *Geons,* 80.

evade certain tasks with the excuse that the chore in question, “might not be the best way for me to spend my time if I am going to earn a scholarship for college.”[110]

Neither should one jump to the conclusion that John Wheeler was above a little mischief—creative and otherwise. As an adult, Wheeler was known to set off firecrackers at unexpected (some might say inappropriate) times and places. Indeed, he was also known to recruit his graduate students as accomplices in these escapades. Warner Miller, who was a student of Wheeler’s at Texas recalls, “Any good student of yours [Wheeler] would have fireworks at home stored in a box somewhere.” Then too, there was the ritual firing of the cannon at Wheeler’s summer home on High Island, Maine.[111]

Teen, and for that matter, middle age mischief notwithstanding, it is clear that several adults, particularly teachers, inculcated a strong work ethic in Wheeler. He speaks fondly of high school teachers in Youngstown such as Mr. Love, the English teacher, Miss Doerschuck, who taught geometry and

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[110] Wheeler and Ford, *Geons,* 83, also 74, 85. On p. 83 Wheeler recalls having paper delivery routes in Ohio and Baltimore, but in his 05 April 1967 interview with Charles Weiner and Gloria Lubkin, 05 Apr 1967, 7, here, Wheeler only recalls delivering papers for one year in Ohio; Wheeler interview with Ford, 09 Dec 1993, 301.

[111] Anecdotes about Wheeler’s fascination with explosive devices and his penchant for setting off fireworks abound. See, for example Wheeler interview with Ford, 06—20 Dec 1993, 204-304]; Warren Miller interview with Kenneth W. Ford, 27 Feb 1995, Miller home in Albequerque, HTML no pagination, http://www.aip.org/history/ohilist/23201.html (19 Nov 2008); Interview with Bryce DeWitt and Cecile DeWitt-Morette interview with Kenneth W. Ford, 25 Feb 1995, University of Texas at Austin, 21.

especially Miss Lida Baldwin, who taught algebra and encouraged Wheeler (and his parents) to make the most of his talent. Wheeler recollects, “They were not the common variety of teacher who treats a fast learner as someone who can safely be ignored or even as someone who is a nuisance.” The first sentence describing Mary Donovan, with whom Wheeler completed the work of four academic years in one calendar year, notes that she walked to school every day from a nearby farm. [112] Reading beyond the text, it seems clear that Mary Donovan's daily slog through the Vermont winter very effectively reinforced other tacit lessons in the value of conscientiousness and diligence.

Even with the influence of these teachers and other adults, most of John Wheeler's work ethic is traceable to his family. In his interview with Ken Ford as well as in *Geons,* Wheeler discusses the pioneering spirit of the Archibald clan—several of whom homesteaded in Kansas as Free-Staters prior to the Civil War. From Kansas, the clan spread to Colorado, New Mexico, and Texas. On his father's side of the family, Wheeler descended from Puritan stock that settled in Massachusetts. He reports that, “within a year of the founding of Concord, Massachusetts (1640), thirty-five Wheeler families lived there. Wheeler was the most common family name in Concord.” Implicit in

[112] Wheeler interview with Ford, 06—09 Dec 1993, 204, 301; Wheeler and Ford, *Geons,* 80.

these family narratives is a high regard for the hard work and perseverance required of settlers in a new land.[113]

Joseph Wheeler seems to have had the most telling influence in this regard. John Wheeler warmly recalls his father's fondness for aphorisms. '"There isn't anything that can't be done better,"' was a favorite along with '"Do what you can, with what you have, where you are."' These stayed with John Wheeler throughout his career as a scientist and a mentor. At the close of the *Geons* chapter describing his youth, Wheeler speaks with particular reverence for his father:

> As I look at my own childhood and wonder what made me think I could grapple with nature's greatest mysteries, I have to give credit to a few teachers who saw some potential in me, and most of all to my father, for whom no mountain was insurmountable. He was no scholar, but he knew how to make his visions come true. ... I grew up in an environment where problem solving and achievement (as well as service) were the respected virtues, where the mind was supposed to do something, not just know something.[114]

Echoes of this creed appeared throughout Wheeler's career.

Indeed, John Wheeler consistently appreciated and encouraged industriousness in those around him. In fact, throughout the autobiography *Geons,* Wheeler nearly always begins the discussion of an individual with an

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[113] Wheeler interview with Ford, 06 Dec 1993, 102-108; Wheeler and Ford, *Geons,* 68-70.
[114] Wheeler and Ford, *Geons,* 84.

assessment of that individual's work habits.[115] Two prominent examples help to illustrate the point.

One such case in point is Ed Cruetz, then a young physicist with whom Wheeler worked on the Manhattan Project. Wheeler notes, "Ed Cruetz was a pleasure to work with. He was ready to sweep floors if that's what it took to get a job done." Based on his evaluation of Cruetz' attitude toward work, Wheeler subsequently recommended him for a senior position at General Atomics corporation. The work habits of the team of young physicists that Wheeler assembled to help in the development of the H-bomb received similar praise. The team included John Toll, now Chancellor Emeritus of the University of Maryland and Ken Ford now-retired executive director of the American Institute of Physics and co-author of *Geons*.[116]

Another example is the theoretical physicist Maria Goeppert-Mayer. Goeppert-Mayer had been one of Wheeler's professors at Hopkins. Later, she became a colleague in the Manhattan Project, and she would win a share of the Nobel prize for physics in 1963 for her work on nuclear shell structure. Unfortunately, Goeppert-Mayer's gender seemed to keep academic promotion out of her reach.[117] Consequently, she waited thirty years to be appointed to a full professorship. Beyond her talent as a physicist, she earned Wheeler's

[115] Wheeler and Ford, *Geons,* passim.
[116] Wheeler and Ford, *Geons,* 218-219.
[117] Wheeler interview with Ford, 20 Dec 1993, 403, 406; Wheeler and Ford, *Geons,* 97.

admiration for remaining positive and enthusiastic about theoretical physics despite the prejudice and devaluation that she endured for the bulk of her career. In *Geons* (1998) Wheeler noted, “To her colleagues she was a valued full partner, whatever status she might be assigned by local administrations.”[118]

At the elite levels of science, the importance of a solid work ethic is matched by the necessity of clear thinking. Are there clues in Wheeler's youth about the way he approached problems? While specific problem solving approaches were imparted to Wheeler later in life, one particularly significant element of thinking style seemed to emerge in his younger years. Fred Archibald, Wheeler's maternal grandfather, was a figure of early significance in this context. John Wheeler, along with his mother and siblings, had two extended stays with his grandparents in Washington, DC. The first occasion occurred when Joseph Wheeler was managing the American Library Association exhibit at the 1915 San Francisco World's Fair. Later (1917 – 1918), while the elder Wheeler was working for the Library War Service, the Wheeler family again lived in the Archibald home. During these intervals, Fred Archibald spent quite a lot of time with his grandson. While John Wheeler was

[118] Wheeler and Ford, *Geons,* 97.

in the first grade, his father “introduced him” to mathematics—including the rudiments of algebra.[119]

More importantly, Wheeler learned from his grandfather how to look at various sides of an issue:

> Sunday dinners at my grandparents' home were special occasions, spiced by political argument. My great-uncle John W. Reid, my grandmother's brother, was a frequent guest at these dinners. He and my grandfather loved to debate issues of the war then in progress. ... My grandfather was an accomplished debater. After convincing everyone of his position over a Sunday dinner, he reversed himself and argued the other side. I was old enough [Wheeler was six at the time] to appreciate the give and take.[120]

Later, as a high school senior in Baltimore, Wheeler performed well on the debate team. In addition to learning to consider a given issue from various perspectives, Wheeler credits this experience with solidifying the self-confidence that is requisite to the practice of science.[121]

Independence of thought, the willingness and ability to consider issues with ‘fresh eyes’ and without regard to conventional wisdom is an important component of careful reasoning. Here, both John Wheeler's parents seem to have had an enduring influence. While attending the first grade in Washington, DC, Wheeler and his classmates were compelled to recite the Pledge of Allegiance. Joseph and Mabel Wheeler found this practice objectionable. For

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[119] Wheeler interview with Ford, 06 Dec 1993, 207. The timeline narrative that runs throughout this session (transcript pages 201-208) put John Wheeler in the first grade at that time; Wheeler and Ford, *Geons,*73.
[120] Wheeler and Ford, *Geons,*74.
[121] Wheeler and Ford, *Geons,*84.

them, compulsory recitation of this oath evoked the specter of state religion in a public school. I would note here that the year is 1917—some thirty-seven years before the U.S. Congress acted to insert the phrase “under God” into the pledge. In the end, though mindful of his parents' convictions, Wheeler kept his own counsel and recited the pledge with the rest of his class.[122]

Later, while walking with his mother in Youngstown, Wheeler observed some workmen connecting pipe in a ditch. Rather than presuming that experienced workers such as these must have known what they were doing, John Wheeler reportedly announced, ‘“They are connecting it wrong. It won't work that way.”’ Someone in the crew heard the comment, examined the work and saw that the boy [Wheeler] was right. The workmen immediately set about to correct the error. As Wheeler notes, such is the stuff of family legends.[123] This last anecdote is, again, standard fare in scientific biography: The young scientist sees something that all the adults miss completely. Still it points to another crucial element in the practice of science or—for that matter—mentoring.

Curiosity is a fundamental prerequisite for a life in science and, John Wheeler possesses an abundance of it. Beginning in his youth, Wheeler was particularly fascinated with mechanical devices. Like many youngsters, he made extensive use of a Meccano set (similar to an erector set) in the

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[122] Wheeler interview with Ford, 06 Dec 1993, 203;Wheeler and Ford, *Geons,*73.
[123] Wheeler and Ford, *Geons,* 82.

construction of all manner of gadgets. In 1920, when Wheeler was nine, he built a crystal radio receiver so that he could hear KDKA Pittsburgh, the first commercial radio station in the United States. Later, guided by Franklin Jones's *Mechanisms and Mechanical Movements* and, working with wood, Wheeler and a high school friend built a combination lock, a repeating pistol, and an adding machine.[124] As impressive as these feats are, an excess of any quality—particularly curiosity—can have its drawbacks.

Wheeler learned this lesson, in somewhat dramatic fashion, on the family farm in Vermont. Along with his fascination with mechanical contraptions, John Wheeler was enticed by explosions. By the time he was four, he had learned that if he put a marble in an empty electric light socket, the marble would shoot out with a pop when he switched the socket on.[125] With his first chemistry set, Wheeler learned to make gunpowder. He learned that a mixture of acetylene and water would blow the cap off a bottle. In Vermont, while Joseph Wheeler and some neighbors were using dynamite to blast holes in the rocky ground for utility poles, John Wheeler was reading extensively about explosives. He knew that the dynamite was set off when a flame burned down a fuse cord to the blasting cap. Therefore, Wheeler

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[124] Wheeler interview with Ford, 06 Dec 1993, 208; Wheeler and Ford, *Geons,* 82-83.

[125] Wheeler interview with Ford, 06 Dec 1993, 203; Wheeler and Ford, *Geons,* 82.

reasoned, if a flame was brought in direct contact with a blasting cap, the cap should explode. Wheeler relates the sequence of events:

> I couldn't resist the temptation. I took two or three dynamite caps from the pig barn and went across the road to a secluded spot in the vegetable garden. I stuck a match in the ground, lit it, and then dropped caps onto it. I kept missing, so I got lower and lower before I released the caps, in hopes of scoring a bull's-eye. Finally, my point of release was only an inch or two above the match flame. With a mighty bang, the cap exploded before I had even let go of it. For weeks afterwards, I was digging little pieces of copper out of my chest and arms and legs. By great good fortune, none of them landed in my eyes.[126]

Although the experiment cost Wheeler the tip of one finger and a small piece of his thumb, it did absolutely nothing to mitigate his fascination with explosions.[127] More importantly, his curiosity remained intact throughout his career.

Another vital quality for a scientist to possess is faith—specifically, the faith that a solution exists for every problem. This faith grew stronger in John Wheeler as a result of one of his part-time jobs. During his last year of high school and throughout his Hopkins years, John Wheeler worked Saturday nights in the public library. His job was help people research technical and/or industrial problems. Wheeler recalls:

> And here is the greatest variety of questions that people bring in to you: “Where can I find out how to build such-and-such?” or “Where can I get the best information on reinforced concrete?” or “How can I tell about anticorrosion metals?” So this business of

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[126] Wheeler interview with Ford, 20 Dec 93, 304; Wheeler and Ford, *Geons,* 81-82; Bernstein, *Quantum Profiles,*101-102.

[127] See note 21. Also, Wheeler and Ford, *Geons,* 82; Jeremy Bernstein, *Quantum Profiles*, 102.

> feeling that anything could be tackled, and, by George, if you just gritted your teeth hard enough, you could find one way or another some information that would help somebody, was very inspiring. I kept on with that and kept learning from it, of course.[128]

John Wheeler's father Joseph played a role here as well (beyond helping Wheeler get the job). Although he does not recall the German phrase *"Die Probleme existieren um überwinden zu werden*" [Problems exist to be overcome] among his father's aphorisms, Wheeler has observed that his father also subscribed to that sentiment.[129] As with curiosity, Wheeler's faith in the existence of a solution for every problem, as will be shown, served his career and his mentees well.

In September 1927, after graduating from Baltimore City College (actually a public high school) John Wheeler enrolled as an engineering major at Johns Hopkins University. He was sixteen years old.

Section 2.3 Johns Hopkins and Karl Herzfeld

John Wheeler never really considered an alternative to Johns Hopkins University for his college education.[130] As the first graduate research university established in America, Hopkins was a prestigious institution which, throughout its history, had attracted an excellent faculty.[131] Perhaps more

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[128] Wheeler interview with Weiner and Lubkin (05 April 1967), 7.
[129] Wheeler and Ford, *Geons,* 67. The translation is Wheeler's.
[130] Wheeler and Ford, *Geons,* 84.
[131] The place of Johns Hopkins in American graduate education is well documented. See Burton R. Clark, ed., *The Research Foundations of*

important to the Wheeler family, Johns Hopkins was located in Baltimore, and therefore, John Wheeler could live at home and save on expenses. The fact that Wheeler was awarded a state scholarship to Hopkins further eased the financial burden on the family. In 1912, as a condition for receiving a bond from the state of Maryland, Johns Hopkins University had committed to establish a '"school or department of applied science and advanced technology."' Johns Hopkins was further obliged to offer some 129 scholarships '"to worthy men of this state."'[132] John Wheeler, in the estimation of at least one local politician, was one of those worthy men.[133] As it turns out,

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Graduate Education: Germany, Britain, France, United States, Japan (Berkeley: University of California Press, 1993); John Calvin French, *A History of the University Founded by Johns Hopkins* (Baltimore, MD: The Johns Hopkins University Press, 1946); Daniel Coit Gilman, *The Launching of a University, and Other Papers: A Sheaf of Remembrances* (New York: Dodd, Mead, & Co., 1906); Hugh Hawkins, *Pioneer: A History of the Johns Hopkins University, 1874-1889* (Baltimore, MD: Johns Hopkins University Press, 2002); Helge Kragh, *Quantum Generations: A History of Physics in the Twentieth Century* (Princeton, NJ: Princeton University Press, 1999); Alexandra Oleson and John Voss, eds., *The Organization of Knowledge in Modern America, 1860-1920* (Baltimore, MD: Johns Hopkins University Press, 1979); Sheldon Rothblatt and Bjorn Wittrock, eds., *The European and American University since 1800: Historical and Sociological Essays* (New York: Cambridge University Press, 1993); Will Carson Ryan, *Studies in Early Graduate Education, The Johns Hopkins, Clark University, The University of Chicago* (New York: The Carnegie Foundation for the Advancement of Teaching, 1939 [Note: Also listed as Bulletin no. 30]); Laurence R. Veysey, *The Emergence of the American University* (Chicago: University of Chicago Press, 1965).

[132] Johns Hopkins University, "Johns Hopkins Chronology" [Online], Available: http://webapps.jhu.edu/jhuniverse/information_about_hopkins/about_jhu/chronology/index.cfm?window=print (06 Jan 2005), n.p.; Wheeler and Ford, *Geons,* 85.

[133] Wheeler interview with Ford, 20 Dec 1993, 306;Wheeler and Ford, *Geons,* 85.

the Hopkins education served John Wheeler's career as a mentor particularly well. Novel approaches to education were factors here.

From the beginning, the focus of Johns Hopkins University had been graduate education. However, for a variety of reasons it was not feasible to exclude undergraduate programs. One innovation was implemented at the inception of the university by its first president, Daniel Coit Gilman. Gilman devised a system in which students could achieve a bachelor's degree after three years of study so they could move quickly into a graduate program.[134] By the time Wheeler arrived at Hopkins, it was possible to “fly non-stop” from freshman to Ph.D. in six years without intermediate degrees (i.e. Bachelor of Arts and/or Master of Arts).[135] Thus, John Wheeler was able to graduate from Johns Hopkins with a Ph.D. in physics before his twenty-second birthday.

The problem however, with staying in the same university for the whole of one's education, is that one can become too indoctrinated to the dominant world-view at that particular institution. This is not always an easy concept for undergraduates to grasp. Richard Feynman, for example was shocked that he couldn't remain at MIT to complete his graduate work. Feynman's re-creation of his conversation about graduate school with John C. Slater, chair of physics at MIT, helps to illustrate the point. The conversation began with Feynman's

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[134] French, *A History of the University Founded by Johns Hopkins*, 137-138; Gilman, *The Launching of a University,* 66-71.
[135] Wheeler and Ford, *Geons,* 86-87.

announcing his intent to apply for admission to the MIT graduate program in physics:

> [**Slater**] We won't let you in here.
>
> [**Feynman**] What?
>
> [**Slater**] Why do you think you should go to graduate school at MIT?
>
> [**Feynman**] Because MIT is the best school for science in the country.
>
> [**Slater**] You think that?
>
> [**Feynman**] Yeah.
>
> [**Slater**] That's why you should go to some other school. You should find out how the rest of the world is.[136]

With the problem of institutional myopia in mind, the physics department at Johns Hopkins established a program that rotated upper division, advanced students from professor to professor, spending a month with each.

This innovative practice insured that, prior to being accepted by a dissertation supervisor, each upper division student had the experience of working with a master in a given field of physics. The cast of characters present at Hopkins at that time is impressive. August Pfund (1879 – 1949; discoverer of Hydrogen Pfund lines) taught physical optics. Robert Wood (1968 – 1955; famous for his ultraviolet light work and the chromospheric flash spectrum) also worked with advanced students in optics. Theoretician Gerhard Dieke (1901 – 1965) showed students how to apply quantum mechanics to atomic and molecular spectra, and Joyce Bearden offered instruction in x-ray

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[136] Feynman and Leighton, *Surely You're Joking Mr. Feynman*, 59.

spectra. Wheeler was introduced to nuclear physics by Norman Feather (1904 – 1978), who was fresh from his Ph.D. work with the Nobelist (and mentor of Niels Bohr) Ernest Rutherford at Cambridge's Cavendish Laboratory.[137] Rutherford in fact, had specifically recommended Feather for the position at Johns Hopkins.[138]

Another objective of rotating students throughout the faculty was for them to become familiar with both laboratory and theoretical techniques.[139] Perhaps most importantly, it also helped aspiring physicists to become accustomed to working with varying methodologies—and personalities. Although Wheeler does not specifically articulate this thought, it seems clear that his working relationships with future mentors and mentees benefited from this exposure to a wide variety of intellects.

For Wheeler, there was yet another advantage in attending Johns Hopkins. Because of its proximity to Washington, there was a long-standing

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[137] Wheeler interview with Weiner and Lubkin (05 April 1967), 11; Wheeler and Ford, *Geons,* 94; W. Norman Brown, comp., *John Hopkins Half-Century Directory: A Catalogue of the Trustees, Faculty, Holders of Honorary Degrees, and Students, Graduates and Non-graduates 1876-1926* (Baltimore, MD: The Johns Hopkins University Press, 1926), 420-423; R. B. Lindsay, "Wood, Robert Williams." *Dictionary of Scientific Biography* Vol. XIV*,* ed. Charles Coulson Gillispie (New York: Charles Scribner's Sons, 1976), 497-499.
[138] Wheeler interview with Ford, 20 Dec 1993, 403-406l Wheeler and Ford, *Geons,* 94; John Archibald Wheeler, "Some Men and Moments in the History of Nuclear Physics: The Interplay of Colleagues and Motivations," working paper, *Nuclear Physics in Retrospect: Proceedings of a Symposium on the 1930's* ed., Roger H. Stuewer (Minneapolis, MN: University of Minnesota Press, 1979): 217-284, 224.
[139] Wheeler and Ford, *Geons,* 94.

relationship between the Johns Hopkins physics department and the scientific staff at the then Bureau of Standards (later the NBS and eventually the NIST).[140] In June of 1930, after Wheeler had completed his third year at Johns Hopkins, he was able to secure a summer job at the Bureau of Standards. For three months, Wheeler had the benefit of working with William F. Meggers (1870 – 1973), a renowned spectroscopist, on diatomic spectrum analysis. As a consequence of this work, and a subsequent paper coauthored with Meggers, by age nineteen, John Archibald Wheeler had become a published scientist.[141] Meggers evidently enjoyed working with Wheeler as well. He invited Wheeler to return to work at NBS for each of the next two summers (1931 and 1932).

The transformation of John Wheeler from future engineer to future theoretical physicist took almost two years. One contributing factor was that, at Hopkins, the physics and engineering departments shared a small library. So, early on Wheeler was exposed to a number of physics texts and journals,

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[140] Wheeler interview with Weiner and Lubkin (05 April 1967), 5; Wheeler and Ford, *Geons,* 107-108; Although the distinction is not made in *Geons*, this agency was officially known as the "Bureau of Standards" during the term of Wheeler's employment. It became the National Bureau of Standards in 1934 and the "National Institute of Standards and Technology" in 1988. See National Institute of Standards and Technology, "NIST at 100: Foundations for Progress," http://www.100.nist.gov/directors.htm (05 Jan 2009).

[141] The paper was: W. F. Meggers and J. A. Wheeler, "The Band Spectra of Scandium-, Yttrium-, and Lanthanum Monoxides." *National Bureau of Standards Journal of Research* 6, (1931): 239-275; See also: Spectroscopist of the Century ... William F. Meggers." *Arcs & Sparks* (21 Nov 2002) [Online]. Available: <http://www.cstl.nist.gov/acd/839.01/meggers.html> (20 Mar 2006); Wheeler and Ford, 97.

many of which he found fascinating.[142] Then there was a chance encounter on campus with Joseph Sweetman Ames, a renowned physicist who, at the time, was serving as president of Johns Hopkins. Ames asked what Wheeler's major was and Wheeler naturally replied that he was in engineering. John Wheeler recalls Ames' response as, “Well, maybe you'll get interested in physics.”[143]

Another factor was the nature of the work in the two disciplines. In 1928, the summer after his first year at Hopkins, John Wheeler worked at a silver mine in Mexico for his uncle John Archibald (for whom he had been named). Wheeler's job was to inspect, maintain, and rebuild the electrical motors that operated the pumps which kept the mine dry enough to work. The mine environment was particularly hard on electrical motors. Therefore, a good deal of Wheeler's time was spent repairing or, more often, replacing the windings of these motors.[144] As he worked, Wheeler began to ponder the sort of problems engineers solved in contrast with the sort of problems physicists solved. In *Geons,* Wheeler recalled his thoughts: “an engineer builds a bridge or whatever it is that lasts 20 or 50 years, but if somebody discovers something in science, well, that's a permanent acquisition of the human

[142] Wheeler and Ford, *Geons,* 86.
[143] Wheeler interview with Weiner and Lubkin (05 April 1967), 4.
[144] Wheeler and Ford, *Geons,* 87-89.

race."[145] In any case, after a summer of winding copper wire around electrical motors, physics began to seem more interesting.

The collegial atmosphere at Hopkins was another factor in Wheeler's decision. The small library that the physics and engineering departments shared also served as a sort of communal work area. There, Wheeler made friends in the in the physics department including Robert Murray. Murray and Wheeler would have long discussions about developments in quantum mechanics. Classes in the physics department, even for undergraduates, tended to be taught in a seminar style. As Wheeler reports, "Students gave the reports instead of the professor talking all the time. So that made a person feel a sense of commitment to what he was talking about."[146] There were also weekly colloquia where a particular topic would be the focus of discussion for the entire academic year. For example, one year (not specified in the source material) Karl Herzfeld, Maria Goeppert-Mayer, and Gerhard Dieke facilitated a seminar on Max Born's treatment of quantum mechanics.[147] The book *Problems of Modern Physics* by the Nobelist Hendrik Antoon Lorentz (1853 – 1928), was another particularly strong influence for Wheeler's move into physics. Finally a coincidental meeting with R. Bowling Brown, who was at the

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[145] Wheeler interview with Weiner and Lubkin (05 April 1967), 7.
[146] Wheeler interview with Weiner and Lubkin (05 April 1967), 6, 8.; Wheeler, "Some Men and Moments in the History of Nuclear Physics," 226.
[147] The particular text is not specified. However a likely candidate is: Max Born and Pascual Jordan, *Elementare Quantenmechanik : Zweiter Band der Vorlesungen Über Atommechanik* (Berlin, Julius Springer, 1930).

time a teaching assistant for Wheeler's physics professor John C. Hubbard (1879 – 1954), sealed the deal. Wheeler officially changed his major at the outset of his third year at Johns Hopkins.[148]

By 1931, Wheeler's career as a scientist was beginning to unfold. He had learned a good deal of physics and acquired a formidable mathematical toolbox. John Wheeler was ready for a mentor and Karl Herzfeld (1892 – 1978), the leading theoretician at Johns Hopkins was ready to have Wheeler as a student.

Karl Herzfeld, who came to the United States in 1926, was among the very first émigré physicists from Europe. Like many European academics, Herzfeld was a son of upper class Vienna. His father had been a prominent Viennese obstetrician and his mother was the daughter of a newspaper publisher. His uncle (on his mother's side) was the famous organic chemist, R. O. Herzog.[149] In 1910, Herzfeld entered the University of Vienna, whose

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[148] Wheeler interview with Weiner and Lubkin (05 April 1967), 8-9; Wheeler and Ford, *Geons,* 86-88; The book cited by Wheeler is, H. A. Lorentz, *Problems in Modern Physics: A Course of Lectures Delivered in the California Institute of Technology by H. A. Lorentz,* ed. H. Bateman (Boston, New York: Ginn and Company, 1927).

[149] Joseph F. Mulligan, "Karl Herzfeld, February 1924 – June 3, 1978." http://newton.nap.edu/html/biomems/kherzfeld.html> (20 Mar 06), also in National Academy of Sciences, *Biographical Memoirs,* Vol. 80 (Washington, DC: National Academies Press, 2001), 160-183; See also Karl Ferdinand Herzfeld (1892 – 1978), "Interview with Dr. Karl Herzfeld," by Bruce Wheaton, 11 May 1978, Washington, DC, transcript, http://www.aip.org/history/ohilist/4669.html (05 Jan 2009), in which Herzfeld notes that his father, "brought the second son of the King of Bulgaria into the world."

theoretical physics department was supervised by Friedrich Hasenöhrl (1874 – 1915). Hasenöhrl had taken over the theoretical professorship after the tragic suicide of Ludwig von Boltzmann (1844 – 1906).

One might expect, given the intellectual legacy of Boltzmann, that Vienna would be the center of statistical physics. Oddly, Herzfeld maintains that he actually mastered the subjects of statistical mechanics and thermodynamics during the time (academic year 1911 – 1912) that he spent working with Otto Stern (1888 – 1969) at the Eigenossische Technische Hochschule (ETH) in Zurich.[150] Stern, who was Einstein's assistant at ETH at the time, later became better known as an experimentalist and won the 1943 Nobel Prize in physics for his work in molecular beams.[151] Herzfeld returned to Vienna and earned his doctorate in 1914, under the direction of Professor Hasenöhrl, with a dissertation that applied statistical mechanics to a gas of free electrons as a model for a theory of metals.[152] But this was hardly Herzfeld's first publication.

Before he even went to Zurich, Herzfeld had published four research papers and prior to completing his doctorate in 1914, he had published two

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[150] Mulligan, "Karl Herzfeld," n.p.; Herzfeld interview with Wheaton, n.p.
[151] Mulligan, "Karl Herzfeld," n.p.; Otto Stern, "Biography," http://nobelprize.org/nobel_prizes/physics/laureates/1943/stern-bio.html (06 Jan 2009), also in *Nobel Lectures, Physics 1942-1962* (Elsevier Publishing Company, Amsterdam, 1964).
[152] Karl F. Herzfeld, "Zur Elektronentheorie der Metalle," *Annalen der Physik,* 4, No: 41, p. 27-52; As per Mulligan, "Karl Herzfeld," this was Herzfeld's dissertation completed under the supervision of Professor Friedrich Hasenöhrl.

more. One of these early research papers included an attempt to derive a model for the hydrogen atom that preceded Bohr's famous 1913 paper.[153] Moreover, Herzfeld continued to write and publish during his four years of service as a heavy artillery officer in the Austro-Hungarian army.[154] After the war, a crumbling economy, social unrest, and the hope of a transition to chemistry led Herzfeld first to Munich, then back to Vienna, and eventually. with the promise of a salaried assistantship, back to Munich to work with theoretical physicist Arnold Sommerfeld (1868 – 1951) and professor of physical chemistry, Kasimir Fajans (1887 – 1975). As Joseph Mulligan, Herzfeld's biographer reports, "He [Herzfeld] impressed both professors so favorably that he was offered a position as Privatdozent in theoretical physics and physical chemistry, combined with an assistantship under Fajans for research in the latter field."[155]

It was an exciting time to be in Munich. At the time, Sommerfeld's students included future Nobel Laureates Hans Bethe (1906 – 2005), Werner Heisenberg (1901 – 1976), and Wolfgang Pauli (1900 – 1958). Mulligan also observes that Herzfeld had a "considerable impact" on Linus Pauling (1901 – 1994) who had come to Sommerfeld's institute as a post-doc on a

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[153] Herzfeld interview with Wheaton; as per Mulligan, "Karl F. Herzfeld", Karl F. Herzfeld, "Über ein Atommodell, das die Balmer'sche Wasserstoffserie aussendet," *Sitzungsberichte der Koniglichen Akademie der Wissenschaften Wien* 121, no. 2a, pp. 593-601.
[154] Mulligan, "Karl Herzfeld," n.p.
[155] Mulligan, "Karl Herzfeld," n.p.; Herzfeld interview with Wheaton, n.p.

Guggenheim Fellowship. Additionally, Mulligan notes that renowned physicists such as Walter Heitler (1904 – 1981), Alfred Landé (1888 – 1976), Otto Laporte (1902 – 1971), and Gregor Wentzel (1898 – 1978) all profited from their association with Herzfeld.[156] Indeed, during the winter of 1922 – 1923, while Sommerfeld took a visiting professorship at the University of Wisconsin, Herzfeld was tapped to deliver the lectures for Sommerfeld's classes in Munich.[157]

And yet, despite this evidently heavy involvement in teaching, Herzfeld was an extraordinarily productive researcher during his Munich years (1919 – 1926). Joseph Mulligan recounts the publication record:

> He published the first modern book in any language on kinetic theory and statistical mechanics (1925), which soon became a very popular graduate-level textbook in German-speaking universities. In the second edition of Hugh S. Taylor's *Treatise on Physical Chemistry*, Herzfeld and H. M. Smallwood wrote the sections on the kinetic theory of gases and liquids and on imperfect gases and the liquid state (1931). During his Munich years Herzfeld also contributed a number of important articles to the *Handbuch der Physik*, including one on Grösse und Bau der Moleküle [Size and Construction of Molecules (1924), another on Klassische Thermodynamik [Classical Thermodynamics] (1926), and a third with K. L. Wolf on Absorption und Dispersion (1928). In addition to the above monograph on the kinetic theory of heat, his *Handbuch* articles, and two articles in the *Handbuch der Experimental Physik,* one of which was a long article on the lattice theory of solids (1928), Herzfeld published over 30 shorter research papers in German journals.

[156] Mulligan, "Karl Herzfeld," n.p.; Herzfeld interview with Wheaton, n.p.
[157] Herzfeld interview with Wheaton, n.p.; Mulligan, "Karl Herfeld," n.p.

Mulligan further notes that because Herzfeld's interests covered such a wide spectrum, there has been a tendency to underestimate his research productivity. [158]

In 1926, Herzfeld was offered a visiting professorship at Johns Hopkins, and as the three month appointment was drawing to a close, Hopkins extended the offer of a permanent position as a full professor. The continuing economic malaise in Germany, coupled with the paucity of opportunities for a permanent position, compelled Herzfeld, then a bachelor, to emigrate to the United States.[159]

At this point, it will be helpful to take note of some patterns that we will see reflected in the career of John Wheeler. The broad range of interests is one example. The tendency to 'leapfrog' to significant problems is another. So is the remarkable level of productivity in research publications. Indeed, Herzfeld's commitment to remain productive in physics while fulfilling his military commitment, is echoed in Wheeler's habit of taking every opportunity to make time for his "Princeton physics" during the years when he was involved in Manhattan and Matterhorn projects. To that point, Ken Ford has remarked that, during Project Matterhorn, Wheeler would often rise as early as 3:00 AM in order to work on his research interests and still fulfill his

[158] Mulligan, "Karl Herfeld," n.p. The translations are by Mulligan.
[159] Herzfeld interview with Wheaton, n.p.

commitment to defense work.[160] Perhaps the most significant indicator of elements that would manifest in Wheeler's career was Herzfeld's commitment to his students.

While the author has yet to uncover any comprehensive reckoning of Herzfeld's students during the ten years (1926 – 1936) that he was at Johns Hopkins, it is clear that Herzfeld had a considerable number of Ph.D. students in his thirty-three years at Catholic University. Joseph Mulligan, author of Herzfeld's "Biographical Memoir" for the National Academy of Sciences, has written that of the eighty-five individuals who received a Ph.D. in physics from Catholic University in the years 1936 – 1962 (when Herzfeld was chair of the department), "almost half" had his or her dissertation supervised by Herzfeld. Moreover, as is often remarked about Wheeler, Herzfeld was generous with both his time and his ideas.[161] There is one other similarity between the two men to address.

Although it is typically not stated explicitly, it is clear that both Wheeler and Herzfeld placed a high value on collegiality and professional relationships. When those conditions deteriorate, as they did at Johns Hopkins in 1935 – 1936 or at Princeton in the wake of the Vietnam War (esp. 1973 – 1975), both

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[160] Wheeler and Ford, *Geons,* 39; Ken Ford, personal communication with author, 31 Dec 2009.
[161] Mulligan, "Karl Herzfeld," n.p.; *Family Gathering,* passim.

men felt compelled to move on.[162] In his biographical memoir for Herzfeld, Mulligan quotes extensively from a letter Herzfeld wrote to his close friend and confidante Sommerfeld, describing the fractious nature of the Department under the stress of economic hardship.[163] Sommerfeld's reply is empathetic, insightful, and includes a touch of humor:

> Das war aber jetzt ein Durcheinander! Nachem ich so lange nicht das Geringste von Ihnen gehört, schrieb ich neulich an Dunlap - aber natürlich noch nach Baltimore - was mit Ihnen los sei, da ich einen hunch hatte, dass Sie in Hopkins abgebaut hatten ... Die Ueberseidlung nach Washington hat natürlich zwei Seiten: die aura spritualis wird Ihnen dort natürlich kongenialer sein, aber wenn das Institut noch im argen liegt, ist das auch kein idealer Zustand ... Vielleicht hat auch die Catholic University einmal Bedarf nach einem Gast-philosophen oder - psychologen, für welchen Fall ich mich bestens empfohlen halte.
>
> [What a mess this is now. I hadn't heard from you in so long that I wrote recently to Dunlap - of course still in Baltimore - [to see] what was going on with you, because I had a hunch that things were coming apart on you at Hopkins … The settlement on Washington naturally has two sides: The spiritual aura may be congenial [to you], but if the institute is in a sorry state, it's not an ideal situation … Perhaps the Catholic University has a need for a guest-philosopher or - psychologists, for which case I am best recommended.][164]

[162] Wheeler and Ford, *Geons,* 316; Mulligan, "Karl Herzfeld," n.p.; Herzfeld interview with Wheaton.
[163] Mulligan, "Karl Herzfeld," n.p. Mulligan quotes from Herzfeld's letter to Sommerfeld of May 19, 1936. As per Mulligan, this letter is in the Sommerfeld Archive at the Deutsches Museum in Munich.
[164] Arnold Sommerfeld to Karl Herzfeld, 21 June 1936, Karl Herzfeld Papers, NBL-AIP. Translation by author.

Despite the experience of difficult times, both Herzfeld and Wheeler seemed to maintain an inherent optimism and to see their colleagues in the best possible light.[165]

As for physics itself, Herzfeld viewed the discipline in the broadest possible context. He was ever mindful of how the topic that was under discussion fit into the larger conceptual realm. In class, he recited that relationship for his students as he began each and every course that he taught.[166] Wheeler remembers that Herzfeld did not deliver ‘canned’ lectures. Rather, Herzfeld's lectures seem to redevelop themselves as he spoke.[167] What seemed to impress Wheeler most of all was Herzfeld's reverence for the enterprise. In an obituary of Herzfeld for *Physics Today*, Wheeler wrote, “Physics for Herzfeld was not a secular, but a religious calling; it aimed, in his view, to make clear the structure and beauty of God's creation.”[168]

Implicit in Herzfeld’s view of physics as a religious calling is the faith in a rational and comprehensible universe. This is the same faith that resonated in Wheeler—a belief that every problem has a solution—from his days in the Enoch Pratt Free Library assisting library patrons who needed answers to technical questions. Wheeler came away from these Saturday evenings with

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[165] See for example, Herzfeld interview with Wheaton, n.p.; Mulligan, “Karl Herzfeld,”; Wheeler with Ford, *Geons,* 316-317;
[166] Wheeler interview with Weiner and Lubkin (05 April 1967), 6.
[167] Wheeler and Ford, *Geons,* 95-96; Wheeler, “Some Men and Moments in the History of Nuclear Physics,” 226.
[168] John Archibald Wheeler, “Karl Herzfeld” [Obituary], *Physics Today* 32, no.1 (Jan 1979), 99.

the strong conviction that, “anything could be tackled, and, by George, if you just gritted your teeth hard enough, you could find one way or another some information that would help.”[169] Of course, whether or not a given problem lies within our capability to solve it is a separate question. The key element to take from this episode is Wheeler's explicit incorporation of the belief that a solution exists for every problem.

Here is also an echo of Einstein. Einstein’s biographer, Abraham Pais, has suggested that, “if [Einstein] had a God, it was the God of Spinoza.”[170] In a letter to his friend, Maurice Solovine, Einstein wrote:

> I can understand your aversion to the use of the term ’religion’ to describe an emotional and psychological attitude which shows itself most clearly in Spinoza. [But] I have not found a better expression than ’religious’ for the trust in the rational nature of reality that is, at least to a certain extent, accessible to human reason.[171]

Inherent in this doctrine of comprehensibility is an optimistic world-view that is an important element of a mentor’s charisma in that it inspires mentees and expands the horizon of the doable. John Wheeler’s Ph.D. work is a fine example of this phenomenon.

For Wheeler’s dissertation, Herzfeld suggested a study of the scattering and absorption of light by helium atoms. Because the calculations involved

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[169] Wheeler interview with Weiner and Lubkin (05 April 1967), 7.
[170] Abraham Pais, *Subtle is the Lord: The Science and Life of Albert Einstein* (New York: Oxford University Press, 1982), 17.
[171] A. Einstein letter to M. Solovine; quoted in John Archibald Wheeler, “Albert Einstein March 14 1879—April 18, 1955.” in National Academy of Sciences, *Biographical Memoirs,* vol. 51 (Washington, DC: National Academy of Sciences, 1980), 101-102.

three bodies (one nucleus and two electrons) this problem involved very complex computations. Beyond these difficulties, Wheeler's dissertation problem offers two important insights. First of all, Wheeler's craftsmanship in the art of problem solving begins to take form:

> As I look back now at that paper written when I was a twenty-one-year-old student, I am startled to find in it approaches to physics that have appeared again and again in my work throughout the rest of my career. First is my way of tackling problems (the practical doer in me). Second is my way of thinking about nature (the dreamer and searcher in me). I fearlessly jumped into mathematical analysis—and surely must have had to learn much of the needed mathematics as I went along. Equally fearlessly, I jumped into numerical calculation. There was, of course, no such thing as a computer at that time, nor even an electrically driven calculator. I used a hand-cranked mechanical calculator.[172]

This passage also demonstrates the sense of the joy with which Wheeler approached his work and the satisfaction that he derived from solving complex problems.

Then too, there is the development of Wheeler's aesthetics in physics and sense of the allure in a problem. He observes, “The problem suggested by Herzfeld had a special charm. It brought out the beautiful connection that exists in physics between absorption and scattering.”[173] The resultant paper, “Theory of the Dispersion and Absorption of Helium,” was submitted to *Physical Review* in January 1933. It is also noteworthy that, despite the tribulations inherent in performing multifaceted numerical calculations in the

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[172] Wheeler and Ford, *Geons,* 100.
[173] Wheeler and Ford, *Geons,* 100.

1930's, John Wheeler was able to predict the refractive index of Helium to within three percent of its currently measured value.[174]

Section 2.4 Gregory Breit

After receiving his Ph.D. from Hopkins, John Wheeler was selected as one of fourteen recipients of National Research Council (NRC) post-doctoral fellowships in physics. As part of the application process, Wheeler was required to make a decision about where he would study. In fact, this was a two part decision. By choosing a location, Wheeler was making a decision about the kind of physics he was going to do, and with whom he was going to work. In the end, although he briefly considered working with Wigner at Princeton, the decision came down to a choice between studying with Robert Oppenheimer (1904 – 1967) in California or Gregory Breit (1899 – 1981) in New York. Wheeler chose Breit and the reasoning is instructive:

> Although I scarcely knew Breit at the time, I had formed a good opinion of him from hearing him speak at Physical Society meetings. I resonated with his style. Like me, he seemed to be always puzzling and was not afraid to let his puzzlement show.[175]

Wheeler's reasons for *not* choosing Oppenheimer help complete the picture:

> There was no doubt about his stature in physics or about his abilities as a teacher. Yet there was something about

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[174] Wheeler and Ford, *Geons,* 100; Wheeler interview with Weiner and Lubkin (05 April 1967), 9; See also J. A. Wheeler, "Theory of the Dispersion and Absorption of Helium." *Physical Review* 43 (1933): 258-263.
[175] Wheeler interview with Ford, 03 Jan 1994, transcript 601-602; The quotation is from Wheeler with Ford, *Geons,*107.

> Oppenheimer's personality that did not appeal to me. He seemed to enjoy putting his own brilliance on display—showing off, to put it bluntly. He did not convey humility or a sense of wonder or of puzzlement.[176]

Clearly, for Wheeler, the process of problem solving was every bit as important—and informative—as the solution itself.

It is useful to keep in mind that physicists are puzzlers and problem solvers by nature.[177] The worst gift one can offer a puzzler is a solved puzzle. Implicit in Wheeler's remarks is a desire to see a mentor's mind at work. Wheeler was savvy enough to know that even if there was only one solution to a problem, there was certainly more than one path to that solution. From that perspective, Oppenheimer's somewhat teleological presentation of a *fait accompli* path to an answer was not only off-putting, it denied Oppenheimer's mentees the opportunity to observe the solution taking shape. Gregory Breit, by contrast, took a more collaborative—perhaps even more social—approach to problems. Working with Breit, Wheeler concluded, would offer him the opportunity to examine multiple pathways to a solution.[178]

That said, Breit was something of a change from Herzfeld. Recall that Herzfeld tended to see a 'grand design' in nature. Wheeler once said of

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[176] Wheeler interview with Ford, 03 Jan 1994, transcript 601-602; the quotation is from Wheeler and Ford, *Geons,*107.
[177] This assertion is corroborated in virtually every scientific biography that has been written from Galileo to Feynman and beyond.
[178] Wheeler, "Some Men and Moments in the History of Nuclear Physics," 229; Wheeler interview with Weiner and Lubkin (05 April 1967), 9-10.

Herzfeld that he [Herzfeld], “had two religions, Catholicism and physics.”[179] Similarly, in nearly all his non-technical writing, Wheeler repeatedly speaks of beautiful solutions or the beauty in nature.[180] However, in Wheeler's case, the pastoral language is misleading. Ken Ford, coauthor of Wheeler's autobiography, speaks of Wheeler the combatant:

> Above all, Wheeler saw physics as a struggle, a challenge. Problems were to be grappled with and conquered. I think he often used the language of contests, or even war. One might see Wheeler vs. nature as analogous to a fencing match or a wrestling match, in which finesse and adroitness counted for a lot and the beauty was in the execution and in the administration of the *coup de grace*.[181]

In any event, Gregory Breit, Wheeler's first post-doctoral mentor, took a far less metaphorical approach to physics.

Like John Wheeler, Gregory Breit did both his undergraduate and graduate training at Johns Hopkins University. Also, both men completed their graduate training at a very young age. Wheeler was twenty-one when he received his Ph.D. and Breit was twenty-two. Unlike Wheeler, who as noted above chose the ‘non-stop’ option at Hopkins (i.e. he did not receive any intermediate degrees on the way to his Ph.D.), Breit earned an A.B. (1918) a M.A. (1920) and a Ph.D. (1921) all from Hopkins. Although it is widely reported

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[179] Wheeler and Ford, *Geons,* 98.
[180] Wheeler and Ford, *Geons,* 84, 148, 236, 355; See also, Wheeler interview with Weiner and Lubkin (05 April 1967), 9, 13, 24, 25, 27, 26; John Archibald Wheeler, “Some Men and Moments in the History of Nuclear Physics,” 224, 226, 227, 250, 255, 260; I believe these three publications from three distinct time periods establish the pattern.
[181] Ken Ford in a 24 Mar 2006 email to the author.

that Gregory Breit had been “trained as an electrical engineer,” his dissertation (“The Distributed Capacity of Inductance Coils”) was supervised by the (then) chair of the Department of Physics and director of the Physical Laboratory, Joseph Sweetman Ames (1864 – 1943), who later (1929 – 1935) served as president of Johns Hopkins University.[182] Some of the confusion about Breit’s training may be due to the fact that his thesis topic, at least on its face, appears to some (including Breit’s biographer, McAllister Hull) more like a study in engineering rather than one in physics. It is also worth noting that Breit completed his dissertation while working as an apprentice in the Radio Division of the (then) Bureau of Standards.[183] Nonetheless, Hull reassures us that Breit’s dissertation is a “masterly piece of applied mathematics,” foreshadowing the skill which, “Breit demonstrated for the rest of his professional life.”[184]

[182] McAllister Hull, “Gregory Breit, July 14, 1899 – September 11. 1981,” http://www.nap.edu/html/biomems/gbreit.html (08 Dec 03) n.p., also in *Biographical Memoirs*, National Academy of Sciences, Vol. 74 (Washington DC: National Academies Press,1998), 26-57; See also Henry Crew, “Joseph Sweetman Ames, 1864 – 1943,” http://books.nap.edu/html/biomems/james.pdf (05 Feb 2009) n.p., also in National Academy of Sciences. *Biographical Memoirs,* Vol. 23 (Washington, DC: National Academies Press, 1944), 180-201.
[183] Per Dahl, “Breit, Gregory,” in *Complete Dictionary of Scientific Biography*, ed. Charles Gillispie, Vol. 19 (New York: Cengage Learning, 2008), 389
[184] Hull, “Gregory Breit,” n.p.

In any case, one gets the sense that Breit brought an engineer's down-to-earth approach to physics.[185] While Wheeler was inclined to wonder about the 'big-picture' implications in the relationships of electrons, positrons, and photons, this kind of reasoning was, as Wheeler delicately phrases it, “not congenial to Breit.”[186] In this respect, Gregory Breit's style as a physicist was more similar to that of Wheeler's intellectual grandfather, Ernest Rutherford than it was to either Herzfeld or Niels Bohr.[187] As far as Breit was concerned, if a phenomenon was not subject to measurement and/or calculation, it was not interesting in a professional sense. Rather than worrying about phenomena

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[185] See Hull, “Gregory Breit,” and Dahl, “Breit, Gregory.” Hull observes that Breit was, “trained as an electrical engineer,” while Dahl reports that Breit received “all three degrees in electrical engineering.” In a personal communication with the author however, Kelly Spring, Assistant Curator of Manuscripts in Special Collections, Milton S. Eisenhower Library, Johns Hopkins University, reports that, as per Johns Hopkins *Half-Century Directory,* all Breit’s degrees were in physics. Spring further reports that the Hopkins Department of Engineering was not established until 1913, and that prior to that time, the department of physics taught courses in what came to be called “electrical engineering.” Spring and university archivist James Simpert speculate that some overlap of course offerings between the departments of physics and engineering continued into the 1920s.

[186] Wheeler and Ford, *Geons,* 119.

[187] See John Archibald Wheeler, “Niels Bohr, the man,” *Physics Today* (Oct 1985), 70. Rutherford held a very matter-of-fact view of physics and was not particularly fond of theorists. “When a young man in my laboratory uses the word 'universe,' “ he [Rutherford] once thundered, “I tell him it is time for him to leave.” “But how does it come,” he was asked on another occasion, “that you trust Bohr?” “Oh,” was the response, “but he's a football player!”

that is too poorly understood for study, physicists should “do what is doable” and calculate the results that can be measured.[188]

This approach to research is likely rooted in Breit’s early career which was dominated by experimental physics. In June of 1925, in an experimental project with Merle Tuve (1901-1982), which established the existence and measured the altitude of the ionosphere, Breit and Tuve unknowingly demonstrated the possibility of radio detection and ranging (RADAR) when they discovered that they received spurious return signals whenever airplanes took off or landed at a nearby airport in Washington, DC. Later, during World War II, both men (though no longer collaborating), capitalized on their knowledge of echo return from pulsed radio signals to assist in the development the proximity fuses used in anti-aircraft artillery. To be clear, Tuve’s work was on the leading edge of research while Breit was more involved in administering the project.[189]

Even so, Breit was a formidable theorist. Writing in 1979, Wheeler said of Breit, “Insufficiently appreciated in the 1930s, he is today the most

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[188] Wheeler interview with Weiner and Lubkin (05 April 1967), 17; Wheeler and Ford, *Geons,* 119; Wheeler, “Some Men and Moments in the History of Nuclear Physics,” 232-233.

[189] Philip H. Abelson, “Merle Anthony Tuve, June 27, 1901 – May 20, 1982,” http://www.nap.edu/html/biomems/mtuve.html (05 Feb 2009), n.p., also in National Academy of Sciences, *Biographical Memoirs,* Vol. 70 (Washington, DC: National Academies Press, 1996), 406-423; Hull, “Gregory Breit,” 39; Dahl, “Breit, Gregory,” 391.

unappreciated physicist in America."[190] As noted above, Breit began as an experimentalist and, like Fermi, he always kept a foot in the experimentalist's camp. Breit's transition to theoretician seems to have begun during a National Research Council post-doctoral fellowship in 1921 – 1922 with Paul Ehrenfest (1880 – 1933) at the University of Leiden. Breit also spent the 1922 – 1923 academic year as a post-doc at Harvard, though it is not clear whom he worked with most closely, if indeed, he had any one particular mentor in that time frame. Whereas both Wheeler's year with Breit in New York and his year with Bohr in Copenhagen seemed consequential to his career, Breit's year in Harvard is acknowledged with only one sentence by his biographers in the *Dictionary of Scientific Biography* and the National Academy of Science's *Biographical Memoirs*.[191] Breit returned to Europe in August of 1928 to accept a residency at the Eidgenössische Technische Hochschule (ETH), Zürich and follow up on some work performed by Wolfgang Pauli and Werner Heisenberg. Per Dahl reports however, that Breit, in view of what he saw as the "untruthful nature of theoretical physics and the need for new data about the nucleus," cut his year abroad short and returned to the United States in January 1929. Evidently, Breit felt that it was more desirable to return to Washington to assist in obtaining this information through investigations into high-voltage developments. Nonetheless, Breit would remain associated with the ETH as a

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[190] Wheeler, "Some Men and Moments in the History of Nuclear Physics," 234; also quoted in McAllister Hull, "Gregory Breit," 27.
[191] Dahl, "Breit, Gregory," 390; Hull, "Gregory Breit," 31.

research associate until 1944.[192] As a theoretician, Breit did some important early work with quantum electrodynamics and later, on nucleonic interactions (i.e. the interaction of two identical particles). Breit's most famous theoretical work was, of course, the set of papers that he and Eugene Wigner published in 1936 on nuclear resonance theory. The Breit-Wigner distribution, describing the cross-section of resonant nuclear scattering, has long been a cornerstone of nuclear studies.[193]

Breit's early work with nucleons (protons and neutrons) was in fact the drawing card for John Wheeler.[194] Early on however, Wheeler became interested in pair theory (i.e. the interaction of light particles such as electrons, positrons, and photons that are external to the nucleus). Later in the year, Breit taught Wheeler how to use Coulomb wave functions as an analytical tool in particle interaction calculations. Despite the change in research focus and the intensive numerical calculations inherent in the later work, it was a very fruitful year. Out of this collaboration with Breit came five papers and a number of ideas that would "haunt [Wheeler] for many years."[195]

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[192] Dahl, "Breit, Gregory," 390-391; Hull, "Gregory Breit," 36-37.
[193] Hull, "Gregory Breit," 49.
[194] Wheeler interview with Weiner and Lubkin (05 April 1967), 10-11.
[195] Wheeler and Ford, *Geons,* 114-115, 119. The papers include: J. A. Wheeler and G. Breit, "Li+ Fine Structure and Wave Functions near the Nucleus," *Physical Review* 44 (1933), 948; J. A. Wheeler, "Interaction Between Alpha Particles," *Physical Review* 45 (1934), 746; G. Breit and J. A. Wheeler, "Collision of Two Light Quanta," *Physical Review* 46 (1934): 1087-1091; F. L. Yost, J. A. Wheeler, and G. Breit, "Coulomb Wave-Functions" *Terrestrial Magnetism* 40 (1935), 443-447; F. L. Yost, J. A. Wheeler, and G.

Unfortunately, Breit was also known to have a temper. John Wheeler, for his part, contends that Breit excluded students from his ire:

> Breit was short, intense, sometimes pugnacious. He had a high forehead and wore small circular eyeglasses. Although he was stubborn and difficult with some of his colleagues, that was a side of him that his research students did not see.[196]

McAllister Hull, like Wheeler, a former student of Breit's, has observed that contrary to John Wheeler's fond memory, there was no special immunity for research students where Breit's temper was concerned:

> Others of my colleagues were not so lucky. Gerry Brown, who remembers Breit as a second father, was regularly a target, and I was present when Gregory took the hide off a graduate student who had wished him 'a good talk' at a meeting: of course his talk would be good! There is no point in detailing more examples: they occurred regularly, and were simply a fact of life for his students (and on occasions) his colleagues.[197]

On the other hand, Hull notes that Breit was quick to apologize and contrite whenever he found himself in the wrong.[198]

Whatever the nature of their relationship when Wheeler served his apprenticeship as Breit's student, the two men did, in fact, have a somewhat spirited disagreement over the issue of a voluntary moratorium on publication of research in nuclear physics at the outset of World War II.[199] Some background will be helpful here.

Breit. "Coulomb Wave Functions in Repulsive Fields," *Physical Review* 49 (1936), 174-89.
[196] Wheeler and Ford, *Geons,* 108.
[197] Hull, "Gregory Breit,", n.p.
[198] Hull, "Gregory Breit," n.p.
[199] Wheeler and Ford, *Geons,* 113;

Gregory Breit was born Gregory Breit Schneider in Nikolayev, Russia, some sixty miles northeast of Odessa on the Black Sea. His father Alfred operated a textbook business. In 1911, after Breit's mother, Alexandra Smirnova Breit Schneider died, the business was sold. The next year Alfred Breit Schneider left his two youngest children (Gregory and his sister Lubov) in the care of a governess, and emigrated to the United States. In 1915, Alfred Breit, having dropped the name Schneider, sent for his children to join him in Baltimore, MD, where he had settled. Besides his sister, Gregory had an older brother, Leo, who chose to avoid conscription in the tsar's army by fleeing through Turkey and joining the (now) Breit family in America.

Gregory Breit, in contrast to his brother, saw the Bolsheviks as the threat to the social fabric of his former country—if not the world writ large. Consequently, as soon as he was of age, the younger Breit sought to enlist in the tsar's army, return to Russia and fight to quell the insurrection. His offer of service was refused by the Russian recruiters "on physical grounds." Time did nothing to diminish these anti-communist sentiments and McAllister Hull (author of Breit's biographical memoir for the National Academy of Sciences), reports that "He [Breit] had a lifelong hatred of Communist Russia: much stronger than the intense distrust that most of us had."[200] Although his political

[200] Dahl, "Breit, Gregory," 389; Hull, "Gregory Breit," 30.

views were somewhat more moderate than those of Gregory Breit, it should be noted John Wheeler shared Breit's deep distrust of Soviet Communism.[201]

Thus, it is not surprising that, alliances aside, Breit saw the Soviet Union as a future, if not a *de facto*, adversary throughout—indeed prior to the U.S. direct involvement in the war. In fact, Breit initiated the discussion over the publication of research in nuclear physics in 1940, mere months after Wheeler and Bohr had published their seminal work on the generalized mechanism of nuclear fission.[202]

In January 1942, immediately after the U.S. declaration of war against Japan, Germany, and Italy, Arthur Holly Compton organized the Metallurgical Laboratory in Chicago. Compton chose Breit to chair the fast-neutron project, supervise bomb studies, and lecture Met Lab staff on bomb theory that might guide plans for a plutonium bomb. In this timeframe, Breit himself contributed important work on isotope separation, neutron diffusion, and chain reactions. Compton also brought in Robert Oppenheimer to serve as a consultant, formally assigned under Breit.

Breit and Oppenheimer were two very different physicists, and the chemistry between them was, to put it mildly, unstable. Breit was concerned that hard-won advances in bomb theory might be leaking out and

[201] The historical record is laden with evidence supporting this assertion. From his work on the H-Bomb, to his involvement in Project JASON, to his support of the Anti-Ballistic Missile System in the late 1960s, John Wheeler was a proto-typical Cold War liberal.
[202] Dahl, "Breit, Gregory," 392.

Oppenheimer was adamant that progress was being hindered because information was not being disseminated in a timely fashion to enough of the people who could make meaningful contributions to the project. Breit resigned from the Manhattan project and moved to Washington where he performed research on ballistics, proximity fuses, and the degaussing of Navy ships as a defense against magnetic mines.[203] Here it bears reiterating that, as with their shared mistrust of Soviet communism, neither John Wheeler nor Gregory Breit was particularly fond of Oppenheimer. The difference was that Wheeler, by nature, was prone to politely indulge the idiosyncrasies of others (e.g. Leo Szilard) while Breit was inclined to be confrontational. In any case, Oppenheimer had plenty of company among those colleagues who were put off by Breit's demeanor.[204]

A final irony must be reported here: Breit was indeed successful in convincing U.S. physicists to cease publishing the results of their research for the duration of the war. Scientific priority would be preserved based on the date a paper was submitted to a journal (e.g. *Physical Review*). Thus, the stream of research publications that had followed in the wake of Bohr and Wheeler's 1939 paper suddenly dried up. Meanwhile, Soviet scientists had been well aware of the war-changing potential of nuclear weapons. Their problem was convincing Soviet leaders that the development of the weapon

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[203] Hull, "Gregory Breit," 28, 40; Dahl, "Breit, Gregory," 392.
[204] Wheeler interview with Ford, 03 Jan 1994, transcript, 502, 504; Wheeler and Ford, *Geons,* 39.

was a worthwhile expenditure of resources in an economy that was barely able (with U.S. assistance) to sustain the burden of war. In the end, it was not the destructive power of nuclear weapons that carried the argument—it was the precipitous silence on the issue of nuclear research in scientific journals. As Richard Rhodes has wryly observed, "secrecy itself gave the secret away."[205]

Returning to the issue of Breit's temper, according to all historical comment, it did not subtract from Breit's devotion to his students. Wheeler, for one, describes Breit as "presiding over a brood of students like a mother hen."[206] McAllister Hull remembers that Breit was very concerned with the health of his students. "Any ailment," Hull notes, "was cause for concern and advice." Dahl, Wheeler and Hull, have all noted Breit was very accessible to students (particularly so in Wheeler's case since he and Breit shared an office) and generous with his time.[207]

Breit also invested a good deal of time in building a sense of community among his apprentices. For example, there were frequent Saturday afternoon excursions to the suburbs of New York which included a vigorous hike through the forest. Wheeler recalls:

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[205] Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Shuster, 1987; reprint, New York: Simon & Schuster, 1995), 500.
[206] Wheeler and Ford, *Geons*, 108.
[207] Dahl, "Breit, Gregory," 389; Hull, "Gregory Breit," 34; Wheeler and Ford, *Geons,* 108-109.

> I don't think we felt we had any choice in this matter, but we would certainly have had no inclination to excuse ourselves from the outings. We saw them as a privilege, not a duty. They provided a wonderful opportunity to get to know Breit as a person, and they knitted us together as a group. Needless to say, physics was not entirely forgotten as we marched through the woods.[208]

Beyond the Saturday afternoon hikes, Breit filled his students' calendars.

There were weekly group lunches which, Hull reports, were sometimes nerve-racking for those who didn't think well on their feet because one never knew when Breit might pose a difficult question.[209] On occasion the group would board a train for Princeton to attend a talk. One evening each week, Breit and I. I. Rabi co-facilitated a joint New York University-Columbia University seminar. Afterward, most of the attendees traveled to Rabi's house to continue the discussion. Breit's wife, Marjorie, actively socialized with the wives of research group members and orchestrated frequent get-togethers for the whole group at the Breit home. In short, Breit's students were socialized professionally (in the Zuckerman sense of the term) by being immersed in physics and the social customs of the physics community.[210]

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[208] Wheeler and Ford, *Geons,* 108-109.

[209] Hull, “Gregory Breit,” 34; Here, Hull is using the memory of former Breit pupil Jack McIntosh. Hull also notes that the lunch-time questions involved a “great deal” of learning “including how to think on our feet!” [The exclamation point originates with Hull].

[210] Zuckerman, *Scientific Elite,* 123.

Section 2.5 Niels Bohr

When John Wheeler had first applied for the NRC postdoctoral fellowship, he had considered spending a year in Leipzig with Werner Heisenberg.[211] After some reflection however, Wheeler chose to start his postdoctoral work in the United States with Gregory Breit. Nonetheless, the plan to study in Europe remained in place. After a few months working under Breit, Wheeler (with Breit's encouragement and support), decided that a year with Niels Bohr (1885 – 1962) in the Copenhagen Institute of Theoretical Physics would benefit his career more than a year with Heisenberg in Leipzig.

Actually, it wasn't much of a decision. By 1934, Copenhagen had become established as the crossroads of theoretical physics in Europe and Germany was no longer an attractive site for Americans abroad. As Breit noted, if Wheeler went to Copenhagen and studied with Bohr, there was a good chance over the course of a year that he would meet most of the leading European theorists, including Heisenberg. On the other hand, if he went to Leipzig and studied with Heisenberg, the chances were rather smaller (especially given the 1934 political climate in Germany) that he would meet many first rank theorists unless he had the time and money to travel.[212]

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[211] Wheeler and Ford, *Geons*, 104.
[212] Wheeler and Ford, *Geons,* 123; Wheeler, "Some Men and Moments in the History of Nuclear Physics," 238.

Then too, over time, Wheeler had come to see Niels Bohr as the foremost theoretician of nuclear physics. On the application to the Fellowship Committee of the National Research Council Wheeler wrote, “Bohr is the best man under whom to investigate the nucleus. He is the man with the great mind and imagination who stimulates and foresees all the others.”[213] It is hard to imagine Wheeler making a more auspicious choice. During the time that Niels Bohr directed the Institute for Theoretical Physics in Copenhagen, from 1921 to 1962, eleven Nobel laureates worked or studied there in the capacity of undergraduate, postdoctoral fellow, or visiting fellow. This list includes Felix Bloch (1905 – 1983), Aage Bohr (1922– ; Aage was, of course, something of a captive audience), Subrahmanyan Chadrasekhar (1910 – 1995), Max Delbrück (1906 – 1981), Werner Heisenberg (1901 – 1976), George de Hevesy (1885 – 1966), Lev Landau (1908 – 1968), Ben R. Mottelson (1926–), Wolfgang Pauli (1900 – 1958), Linus Pauling (1901 – 1994), and Harold C. Urey (1893 – 1981). While the character of each relationship with Bohr varied,

[213] While the sentiment remains constant, there are varying versions of this statement. c.f. Wheeler interview with Ford, 03 Jan 1994, transcript, 606; Wheeler and Ford, *Geons,* 123; Wheeler interview with Weiner and Lubkin (05 April 1967), 17-18; Wheeler interview with Aaserud (04 May 1988), n.p.; Wheeler, “Some Men and Moments in the History of Nuclear Physics,” 238;

all but two (Chandrasekhar and Mottelson) acknowledged the work with Bohr in their Nobel biography.[214]

[214] Felix Bloch, "Biography", http://nobelprize.org/physics/laureates/1952/bloch-bio.html (24 Mar 06), also in *Nobel Lectures, Physics 1942-1962* (Amsterdam: Elsevier Publishing Co., 1964); Aage Bohr, "Autobiography", http://nobelprize.org/physics/laureates/1975/bohr-autobio.html (24 Mar 2006), also in *Les Prix Nobel*, ed. Wilhelm Odelberg (Stockholm: Nobel Foundation, 1976); David C. Cassidy, *Uncertainty: The Life and Science of Werner Heisenberg* (New York: Freeman, 1993); Subrahmanyan Chandrasekhar, "Autobiography ", http://nobelprize.org/physics/laureates/1983/chandrasekhar-autobio.html (24 Mar 2006), also in *Les Prix Nobel* ed. Wilhelm Odelberg (Stockholm: Nobel Foundation, 1984); Max Delbrück, "Biography", http://nobelprize.org/medicine/laureates/1969/delbruck-bio.html (24 Mar 06), Also in *Nobel Lectures, Physiology or Medicine 1963-1970* (Amsterdam: Elsevier Publishing Company, 1972); Werner Heisenberg, "Biography", http://nobelprize.org/physics/laureates/1932/heisenberg-bio.html (24 Mar 2006), also in *Nobel Lectures, Physics 1922-1941* (Amsterdam: Elsevier Publishing Co., 1965); George de Hevesy, "Biography", http://nobelprize.org/chemistry/laureates/1943/hevesy-bio.html (24 Mar 2006), also in *Nobel Lectures, Chemistry 1942-1962* (Amsterdam: Elsevier Publishing Co., 1964); Lev Landau, "Biography", http://nobelprize.org/physics/laureates/1962/landau-bio.html (24 Mar 2006), also in *Nobel Lectures, Physics 1942-1962* (Amsterdam: Elsevier Publishing Co., 1964); Ben R. Mottelson, "Autobiography", http://nobelprize.org/physics/laureates/1975/mottelson-autobio.html (24 Mar 2006), also in *Les Prix Nobel en 1975*, ed. Wilhelm Odelberg (Stockholm: Nobel Foundation, 1976); Abraham Pais, *Niels Bohr's Times in Physics, Philosophy, and Polity* (New York: Oxford University Press, 1991); Wolfgang Pauli, "Biography", http://nobelprize.org/physics/laureates/1945/pauli-bio.html (24 Mar 2006), also in *Nobel Lectures, Physics 1942-1962* (Amsterdam: Elsevier Publishing Co. 1964; Linus Pauling, "Biography", http://nobelprize.org/chemistry/laureates/1954/pauling-bio.html (24 Mar 2006), also in *Nobel Lectures, Chemistry 1942-1962* (Amsterdam: Elsevier Publishing Co., 1964); Harold C Urey, "Biography", http://nobelprize.org/chemistry/laureates/1934/urey-bio.html (24 Mar 2006), also in *Nobel Lectures, Chemistry 1922-1941* (Amsterdam: Elsevier Publishing Co., 1966).

Bohr, like Herzfeld, assumed a broad world view in physics. As Wheeler has stated:

> And of course there was a completely different spirit between Bohr's approach to nuclear physics and Breit's—Bohr looking over the whole thing without getting down to detailed calculation on any one aspect and always looking for a paradox that would throw light on *a* whole new approach, and Breit, on the other hand, focusing on a very careful comparison of a detailed model with experiment and the soul of integrity and giving one the feeling that any part of physics should in principle, if one understood it properly, be subject to calculations so you could really hope to check the theory against your experiment and not just talk.[215]

And yet talk was intrinsic to Bohr's methodology of physics.

As the product of five generations of academicians, Niels Bohr acquired the practice of scholarly dialogue very early in life. His father, Christian Bohr, a renowned Danish scientist, had been nominated for a Nobel prize twice (1907, 1908) for his work on the physiology of respiration. Christian Bohr was also a prominent member of the Videnskabernes Selskab [the Royal Danish Academy of Sciences and Letters]. After academy meetings, Bohr would often invite a number of colleagues to his home for extended discussions. This after-meeting meeting usually included the famous philosopher of religion Harald Höffding, the physicist Christian Christiansen, and the linguist Vilhelm Thomsen. As soon as they were old enough to benefit from the conversation, Niels Bohr and his younger brother Harald were permitted to sit in on these

[215] Wheeler interview with Weiner and Lubkin (05 April 1967), 17.

discussions.[216] It appears that the Bohr sons were subjected to tacit learning at an early age. It would also appear that the habit of auditory analysis stuck.

Throughout his career, Bohr seemed to need to verbalize concepts as if by hearing them spoken he could detect the presence or absence of a “ring of truth.” The physicist Abraham Pais, who is also Bohr's biographer, and John Wheeler have both noted that Bohr worked best when at least one other physicist was present to serve as a sounding board.[217] Wheeler observes:

> He always liked to have at least one other person present, even if he were lost in his own thoughts. When the moment came that he wanted to pull forth an idea and examine it, he needed a foil, someone with whom he could toss the idea back and forth. Léon Rosenfeld filled this role for some years. So did Bohr's son Aage.[218]

Where Gregory Breit had subjected concepts to trial by calculation, Niels Bohr employed trial by oration.

Whenever and wherever Bohr set to work, the day would begin with verbally rehearsing the arguments that formed the basis for quantum and/or nuclear theory. Since Bohr had been an accomplished football (soccer) player, this ritual is often described with athletic metaphors. Abraham Pais describes

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[216] Abraham Pais, *Niels Bohr's Times in Physics, Philosophy, and Polity* (New York: Oxford University Press, 1991), 33-36, 98-99. See also: Leon Rosenfeld, “Bohr, Niels Henrik David,” in *Dictionary of Scientific Biography* vol. II, ed. Charles Coulston Gillispie (New York: Charles Scribner’s Sons, 1975), 239-254

[217] Pais, *Niels Bohr's Times,* 3, 7-8, 421-422; Wheeler interview with Ford, 10 Jan 1994, transcript, 607, 702; Wheeler and Ford, *Geons,* 126; John A. Wheeler, “ 'No Fugitive and Cloistered Virtue'—A Tribute to Niels Bohr,” *Physics Today* 16, no. 1 (Jan 1963), 31; Wheeler, “Niels Bohr, the Man,” 66-72

[218] Wheeler and Ford, *Geons,* 126.

Bohr's practice as “an athlete warming up before entering the sports arena.”[219] John Wheeler, who also tended to view physics as a contest, saw Bohr's custom as a more vigorous endeavor. Wheeler characterized Bohr's routine as “a one-man tennis match.”[220]

There was another element of Bohr's method which, for Wheeler, must have induced fond memories—even if only at a subliminal level. In order to ferret out the weakness or contradictions in a hypothesis, Bohr would temper concepts by alternatively building them up and then tearing them down. Wheeler offers a synopsis of the process:

> Usually the new issue became a focal point for discussion in the next days. Those days could almost have been numbered odd and even. One day was a day of building. “If so-and-so is true, such-and-such follows. That will give us the chance to understand thus-and-so. That means it will be absolutely central to measure this-and-this cross section. Then we will be able to predict such-and-such with great assurance.” No criticism. That was reserved for the next day. If at its end anything survived, that battle-tested core became the starting point of yet another day of building—and so on, up to a conclusion that could be played out as a complete tennis match.[221]

Although Wheeler does not articulate the thought, Bohr's method of alternatively supporting and attacking a concept was reminiscent of Sunday evenings in Baltimore when Wheeler's grandfather Archibald would promote

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[219] Pais, *Niels Bohr's Times,* 8.
[220] Wheeler, “Niels Bohr, the man,” 66.
[221] Wheeler, “Niels Bohr, the man,” 68. See also. Edwin F. Taylor, “The Anatomy of Collaboration,” in *Magic Without Magic: John Archibald Wheeler; A Collection of Essays in Honor of His Sixtieth Birthday,* ed, John R. Klauder (San Francisco: W. H. Freeman, 1972): 474-485, 477.

one side of a political argument before dinner and attack it afterward.[222] By this practice, Bohr tacitly communicated to his students the manner by which raw concepts must be refined before they can be woven into the tapestry of science.

Even paper writing was an intensely verbal endeavor. From the outset, Bohr seldom wrote papers in the sense of putting pen to paper. Instead, he preferred to dictate to an amanuensis of the moment. If Rosenfeld or Aage Bohr were not available, Bohr would enlist whomever he could find. Pais suggests this was, at least in part, a consequence of Bohr's poor penmanship. [223] However, Bohr's wife Margrethe recalls that, '"he had so much in his head that just had to be put down, and he could concentrate while he dictated."'[224] Since there has been no evidence presented that Bohr evaluated the penmanship of his 'scribes', Margrethe Bohr's recollection is more resonant with the widely acknowledged need for Bohr to think aloud.

Certainly getting a new idea onto paper was no guarantee of imminent publication for either Bohr or his collaborators. The editing process with Bohr could be extraordinarily thorough. According to Pais, Bohr defined a manuscript as "a document on which to make corrections."[225] Two factors were at play. One element, very likely stemming from his boyhood

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[222] Wheeler and Ford, *Geons,* 74.
[223] Pais, *Niels Bohr's Times,* 10, 102-103.
[224] Pais, *Niels Bohr's Times,* 102-103.
[225] Pais, *Niels Bohr's Times,* 103.

conversations with the philosopher Harald Höffding and the linguist Vilhelm Thomsen, was that Bohr was acutely sensitive to the nuances in the spoken and written word. Pais recalls Bohr's thoughts on the matter:

> What is it that we human beings depend on? We depend on our words. We are suspended in language. Our task is to communicate experience and ideas to others. We must strive continually to extend the scope of our description, but in such a way that our messages do not thereby lose their objective or unambiguous character.[226]

Plainly, for Bohr, word choice was more than mere auditory cosmetology. It seems safe to surmise that by repeated revisions, Bohr was tacitly communicating the importance of craftsmanship in language. On a less esoteric plane, there is also the story of Wheeler and Bohr, in the spring of 1939, combing through dictionaries in Princeton's Fine Hall for more than an hour because Bohr disliked the term “fission” for the splitting of a nucleus. Wheeler recalls, ‘“If fission is a noun,' he said to me, 'what is the verb? You can't say 'a nucleus fishes!”’[227] Despite their heroic efforts to find a suitable verb, the noun 'fission' has endured.

Of course, language was secondary to accuracy. Science historian Gerald Holton has listed four reasons why he sees Niels Bohr as an exemplar of scientific integrity. The very first (and presumably most significant) rationale Holton offers is that Bohr tried, “to get it right at all costs, sparing no effort.” As a corollary to this notion, Holton maintains that once a concept has been

[226] Pais, *Niels Bohr's Times, 445-446.*
[227] Wheeler and Ford, *Geons,* 21-22.

thoroughly tested, one must also possess the courage of conviction to hold to one's hypothesis even “before it is fashionable or safe.” To support his contention, Holton cites the 'Bohr atom' paper of 1913 as a novel concept that was rigorously examined and submitted to a very skeptical community.[228]

Wheeler got the message. In *Geons,* Wheeler recalls that Bohr had “little concern for priority.” Rather he preferred to “ruminate on a topic at length, patiently polishing its details.” This, of course is in stark contrast to the typical late twentieth century physicist—especially one just embarking on a career—for whom precedence in publication is an (albeit justified) obsession. In fact, a common practice is to publish something—even a letter to the *Physical Review Letters* and fill in the details later.[229] As it turns out, during their time in Copenhagen (1934 – 1935), Wheeler and Milton Plesset had written a paper on gamma-ray (high-energy photons) scattering in interactions with atomic nuclei. In the early days of cosmic ray research, they believed that they had made significant progress in an area of interest. Bohr however, believed that more could and should be done before the paper was submitted to a journal. Although Wheeler and Milton worked at the refinements

[228] Gerald Holton, “Niels Bohr and the Integrity of Science,” *American Scientist* 74, no. 3 (May-Jun 1986), 240

[229] Wheeler and Ford, *Geons,* 129-130; Caltech Vice-Provost David Goodstein in a 17 Mar 2006 email to the author, reports that if a scientist has one or two real contributions to make, they will divide them up into a number of letters which are submitted in advance of the main papers.

suggested by Bohr, they ultimately ran out of time, and their work went unpublished.[230]

A similar situation arose in the spring of 1939. Bohr and Wheeler had collaborated on the first study of the generalized mechanism of nuclear fission.[231] Unfortunately, Bohr needed to return to Denmark in April of 1939, well before the editing process was complete. Wheeler recalls (with a hint of pride):

> Bohr's usual habit to go back and forth with his coauthors, often for an extended period, as he struggled for the precision, generality, and clarity that he always held forth as a goal. This time, uncharacteristically, he gave me permission to edit and submit the paper without sending the final version to him for review.[232]

Wheeler also reports that Victor Weisskopf (1908 – 2002) and Rudolph Peierls (1907 – 1995), two physicists familiar with Bohr's work habits, were amazed (and envious) when they learned how smoothly the fission paper had been handled. The paper was submitted in June of 1939 and published on 1 September 1939, the day that Germany invaded Poland and World War II began.[233]

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[230] Wheeler interview with Ford, 03 Jan 1994, transcript, 608; Wheeler and Ford, *Geons,* 129-130. It should be noted here that Wheeler's bibliography does in fact contain a paper written with Milton Plesset ("Inelastic Scattering of Quanta with Production of Pairs, *Physical Review* 48, no. 4 (15 Aug 1935), 302-306), which was received from the Institute for Theoretical Physics in Copenhagen, Denmark on 12 Jun 1935.

[231] The paper in question is: N. Bohr and J. A. Wheeler, "The Mechanism of Nuclear Fission," *Physical Review* 56, No. 5 (01 Sep 1939), 426-450.

[232] Wheeler and Ford, *Geons,* 31.

[233] Wheeler and Ford, *Geons,* 31-32.

In June of 1935, John Wheeler left Copenhagen for the United States. His fiancé, Janette Hegner, and an assistant professorship at the University of North Carolina awaited his return. John Archibald Wheeler was ready to become a mentor. He was twenty-four years old.

Section 2.6 Einstein's Protégé

Two commonplaces in the historiography of Albert Einstein are; 1) he had no apprentices and 2) by the time he emigrated to the United States, he was no longer in the forefront of theoretical physics. This latter sentiment was almost certainly (at least in part) a carry-over from the 1927 Solvay Congress during which Niels Bohr had clearly won the great debate with Einstein over the validity of quantum theory.[234] Recall that in a 4 December 1926 letter to Max Born, Einstein famously asserted:

> Quantum mechanics is very impressive. But an inner voice tells me that it is not yet the real thing. The theory produces a good deal but hardly brings us closer to the secret of the Old One. I am at all events convinced that He is not playing at dice.[235]

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[234] Kragh, *Quantum Generations,* 213.

[235] Albert Einstein, Max Born, and Hedwig Born *The Born Einstein Letters: Correspondence between Albert Einstein and Max and Hedwig Born from 1916 to 1955 with Commentaries by Max Born,* trans. Irene Born (New York: Walker and Company, 1971), 90-91; This particular sentence is quoted in virtually every biography of Einstein as well as in countless other texts. Two more scholarly examples are: Pais, *Subtle is the Lord,* 443 and Pais, *Niels Bohr's Times,* 318.

Einstein's decline in status was not so much a result of his loss in the debate as it was in his adamant (some might say 'stubborn') disavowal of the quantum mechanical world view.

Albeit very gently, John Wheeler acknowledged Einstein's diminished influence in a series of talks which marked the centenary of Einstein's birth. In an 8 May (1979) lecture at Leed's University, Wheeler described his first meeting with Einstein. It was in the autumn of 1933; Wheeler was a post-doc studying with Gregory Breit and Einstein had just recently emigrated to the United States. The meeting came about on one of Breit's periodic sojourns away from the NYU campus.[236] Breit and his students were invited to a "carefully unannounced" seminar in which Einstein would discuss his latest work. Reflecting on Einstein's remarks, Wheeler observed, "It was clear on this first encounter that Einstein was following very much his own line, independent of the interest in nuclear physics then at high tide in the United States." In an interview with Ken Ford, in preparation for writing *Geons,* Wheeler was more direct, "I didn't get the feeling he had any great vision that one could subscribe to or develop or go on with. He seemed to be trying equations on the wholesale scale without any great physical idea to guide it."[237] Put simply, in

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[236] Wheeler, "Some Men and Moments it the History of Nuclear Physics," 232; Wheeler and Ford, *Geons,* 108-109, 111-112.

[237] John Archibald Wheeler, "Einstein: His Strength and His Struggle," working paper, Twentieth Selig Brodetsky Memorial Lecture, University of Leeds, 8 May 1979 (Leeds, UK: Leeds University Press, 1980), 3; John Archibald Wheeler, "Albert Einstein March 14 1879—April 18, 1955." in National

the view of Wheeler and many of his colleagues, physics seemed to have moved beyond Einstein.

In 1936, while teaching at North Carolina, Wheeler applied for a leave of absence so that he could accept a visiting appointment to the Physics department Princeton. John Wheeler intended this "mini-sabbatical" to allow him to complete some thinking and writing about nuclear physics without the encumbrance of classroom responsibilities. Wheeler also intended to establish a personal relationship with the theoretician Eugene Wigner (1902 – 1995) and the mathematicians Herman Weyl (1885 – 1955) and John von Neumann (1903 – 1957). Despite his first impression of Einstein as being beyond his prime, in *Geons,* Wheeler claims that he wanted to get to know Albert Einstein even though, "our interests were then so different that I didn't expect to learn very much from him."[238] So, why would Wheeler want to better know a man from whom he drew a lackluster first impression and "didn't expect to learn very much?"

One important part of the attraction Wheeler felt for Einstein was that they shared world-view based on comprehensibility:

> There was one extraordinary feature of Einstein the man I glimpsed that [first] day, and came to see ever more clearly each time I visited his house climbed to his upstairs study, and we explained to each other what we did not understand. Over and

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Academy of Sciences, *Biographical Memoirs,* vol. 51 (Washington, DC: National Academy of Sciences, 1980), 99; Wheeler and Ford, *Geons,* 111-112; Wheeler interview with Ken Ford, 03 Jan 1994, transcript 604.

[238] Wheeler and Ford, *Geons*, 150.

> above his warmth and considerateness, over and above his deep thoughtfulness, I came to see, he had a unique sense of the world of man and nature as one harmonious and someday understandable whole, with all of us feeling our way forward through the darkness together.[239]

This sentiment is the very same doctrine of comprehensibility that was evident in Herzfeld's 'faith' in physics. It is the same conceptual optimism—the belief that anything can be tackled and further, that sooner or later every problem will yield a solution—that grew out of Wheeler's work as an assistant librarian for technical literature in Baltimore. Finally, in a March 1979 lecture John Wheeler extolled Einstein and several other scientists and inventors specifically because they approached their work with a "larger"—and therefore more comprehensive—frame of reference.[240]

The dynamics of John Wheeler's relationship with Einstein changed when, according to his own metaphor, Wheeler came under the conceptual influence of gravity (as it is understood in general relativity). This attraction to gravity came about as consequence of Wheeler's work in nuclear physics. Early in 1952, he revisited two 1939 papers by Robert Oppenheimer (one with George Volkoff, the other with Hartland Snyder) that predicted the gravitational collapse of a star that had consumed its nuclear fuel. Wheeler believed that the mathematical singularity predicted by Oppenheimer and his associates had to be incorrect, and he set out to rectify the situation. Wheeler observed, "I

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[239] Wheeler, "Albert Einstein March 14 1879—April 18, 1955," 99-100; Wheeler, "Einstein: His Strength and His Struggle."3-4.

[240] John A. Wheeler, "Einstein and other seekers of the larger view," *Science and Public Policy* 6 (Dec 1979), passim.

wanted to teach relativity for the simple reason that I wanted to learn the subject." On 6 May 1952, Wheeler obtained permission to teach a graduate level course in general relativity.[241]

From the outset of the course, Wheeler and his students worked to get beyond the mathematical formalism that had come to dominate the subject.[242] In this endeavor, Wheeler found a kindred spirit in Einstein. Although Einstein's name is forever linked to equations—one in particular—he was not (at least by professional standards) a particularly skilled mathematician. Like Bohr (and unlike Breit) Einstein approached physics through intuition and articulated concepts rather than through applied calculation. The mathematician David Hilbert once remarked, "Every boy in the streets of our mathematical Göttingen understands more about four-dimensional geometry than Einstein. Yet, despite that, Einstein did the work and not the mathematicians."[243] Why would this be true?

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[241] For quotation, see Wheeler and Ford, *Geons,* 228-229; for permission to teach relativity, see Wheeler notebook "Relativity I", p 1, "6 May 1952 [Underlining in original] 5[55]pm. Learned from Shenstone ½ hour ago the great news that I can teach relativity next year. I wish to give the best possible course. To make the most of the opportunity, would be good to plan for a book on the subject. Points to be considered: (1) a short introductory outline of the whole (2) Emphasis on the Mach point of view (3) Many tie-ups with other fields of physics. Mention these in class; in the book put them in the ends of chapters as examples. Show [correct word ?] simplifying, APS-JAW.
[242] Wheeler and Ford, *Geons,* 228, 231.
[243] Philipp Frank, *Einstein, Sein Leben undseine Zeit* (München: Paul List Verlag, 1949), p. 335, quoted in Wheeler, "Einstein: His Strength and His Struggle," 5.

Wheeler suggests that Einstein's years of work in the patent office forced him to adopt a world-view that was more general (and therefore more comprehensive) than that held by the mathematicians who, at least professionally, were more narrowly focused. For seven years, on a daily basis, Einstein was required to examine novel (or not-so-novel) attempts to apply the laws of physics in everyday life. As concisely as possible, he would have to explain to the patent applicant why the invention was (or was not) worthy of a patent. In the course of denying a patent, Einstein was often obliged to explain some general principle of physics that rendered the applicant's invention unworkable.[244] It is also worth noting here that Einstein and Wheeler shared a youthful (and probably lifelong) fascination with mechanical contraptions.[245]

The dividends of Wheeler's choice to explore relativity from a generalist's (i.e. conceptualist) world-view were handsome. Over the course of that first year, Wheeler quickly realized that decades of a strict mathematical treatment of relativity had only just scratched surface of relativity's conceptual bounty:

> What I learned in teaching the course was that the riches of Einstein's theory had been far from fully mined. Hidden beneath the equations, simple in appearance, complex in application—was a lode waiting to be brought to the surface and exploited.[246]

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[244] John Archibald Wheeler, “Albert Einstein March 14 1879—April 18, 1955.” in National Academy of Sciences, *Biographical Memoirs,* vol. 51 (Washington, DC: National Academy of Sciences, 1980), 102-103.
[245] Wheeler and Ford, *Geons,* 83; Wheeler, “Albert Einstein March 14 1879—April 18, 1955,” 100-101.
[246] Wheeler and Ford, *Geons,* 231.

Small wonder that the enterprise of unearthing this lode dominated the next quarter century of John Wheeler's life.

Wheeler and Einstein also shared a high regard for the value of colleagueship. This colleagueship, it must be noted, included the participation of students in a seminar format. Wheeler asserts, “No tool of colleagueship is more useful than the seminar.” In such a context, professors are not to pontificate from a pedestal. Rather, Wheeler declares that a seminar setting obligates students to question their professors. In the end, Wheeler and Einstein agreed that theoretical constructs are best strengthened (or most efficiently eliminated) by the rigorous examination of both students and peers.[247]

Given their mutually held fondness for the seminar method of investigation, it is not surprising that Einstein made himself available to Wheeler's relativity seminar twice in the last years of his life. The first of these was on 16 May 1953, when Einstein invited Wheeler's seminar group over to his house for tea. The following year, on 14 April 1954 (one year and four days before his death), Einstein addressed Wheeler's seminar group in Fine Hall on the Princeton campus.[248]

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[247] Wheeler, “Albert Einstein March 14 1879—April 18, 1955,” 103-104.

[248] John A. Wheeler, “Mercer Street and other Memories,” in *Albert Einstein: His Influence on Physics, Philosophy, and Politics,* ed. Peter C. Aichelburg and Roman U. Sexl (Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979), 202; Wheeler, “Einstein: His Strength and His Struggle,” 104.

One example of the benefits that colleagueship with Einstein provided stands out for Wheeler. In response to a question regarding radiation damping, Einstein referred Wheeler to a 1909 article in which he and Walter Ritz set out their respective positions clearly and distinctly. The dialogue was summed in one sentence, '"Ritz treats the limitations to retarded potentials as one of the foundations of the second law of thermodynamics, while Einstein believes that the irreversibility of radiation depends exclusively on considerations of probability."'[249]

Three other examples of the nature of John Wheeler's relationship with Einstein are useful to this discussion. One such instance is John Wheeler's invitation to author Einstein's biographical memoir for the National Academy of Sciences. Obviously a large number of academy members were capable of writing Einstein's memoir; the fact that John Wheeler was chosen certainly seems significant.

Some background on author selection for these memoirs may prove illuminating. In the National Academy of Science, selecting an author for a given Biographical Memoir falls to the scientific peers of the deceased. The academy is divided into twenty sections (ranging from applied physics to plant biology) that correspond to the various sub-disciplines of science recognized by the academy. To assign a memoir, the chair of the appropriate section (in

[249] A. Einstein and W. Ritz, *Physikalisches Zeitschrift,* 10 (1909): 323-34, quoted in Wheeler, "Albert Einstein March 14 1879—April 18, 1955," 104.

Einstein's case, physics) works with other members in that section to identify someone who “has an intimate knowledge of the life and scientific work of the deceased.” It is also noteworthy that in order to choose the individual best qualified (i.e. one with an 'intimate' knowledge of the deceased), the members of a section are free to choose authors who are not members of the National Academy of Sciences.[250] It is significant that from this relatively large pool of authors who had intimate knowledge of Einstein’s life and work, John Wheeler was selected to be the author of the Einstein’s Biographical Memoir

Another example of Wheeler's affection for Einstein is found in *Albert Einstein: His Influence on Physics, Philosophy, and Politics,* edited by Peter C. Aichelburg and Roman U. Sexl, which appeared in 1979—the centenary year of Einstein's birth. The book contained sixteen chapters, which were contributed by fifteen authors. I note here that John Wheeler, unlike the other contributors, submitted two chapters to this volume. These were, “Black Hole: An Imaginary Conversation with Albert Einstein”, and “Mercer Street and Other Memories.”[251] The latter selection is a fond remembrance of Wheeler's relativity class joining Einstein for tea in his Mercer Street home. The former selection is more telling of the relationship. Certain passages in this dialogue very much have the flavor of a junior colleague reporting to a mentor:

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[250] Stephen Mautner, Executive Editor of National Academies Press, Joseph Henry Press, 13 April 2006, in voice mail to author (10:59 AM PDT).

[251] Peter C. Aichelburg and Roman U. Sexl, eds., *Albert Einstein: His Influence on Physics, Philosophy, and Politics* (Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979).

> [**Wheeler**] I and my colleagues have to confess that we have made only a bare beginning at studying the approach to singularity both in cosmology and in black hole physics.
>
> [**Einstein**] To understand that approach is really important.
>
> [**Wheeler**] Our Soviet colleagues propose fascinating physical insights as to what goes on in the final stages of collapse, but not convincing mathematical methodology. Colleagues in the West have the mathematical methodology but so far it has not sufficed to provide the insight that we all want.
>
> [**Einstein**] This is an old story in physics. We know in the end everything comes together in a new and better and larger unity.

And further:

> [**Wheeler**] I don't have to tell you that there is still a non-negligible body of our colleagues who think that an asymptotically flat universe is more natural than a closed universe.
>
> [**Einstein**] But that view takes the geometry of faraway space out of physics and makes it part of theology, to be discovered by reading Euclid's bible. It puts us back to the days before Riemann, days when space was still for physicists, a rigid homogeneous something, susceptible of no change or conditions. Only the genius of Riemann, solitary and uncomprehended, had already won its way by the middle of the last century to a new conception of space, in which space was deprived of its rigidity, and in which its power to take part in physical events was recognized as possible.

Finally:

> [**Wheeler**] But whether you call particles geometry or something else, does it not trouble you that collapse should mean their end?
>
> [**Einstein**] To me the problem of collapse is no greater than the problem of the big bang. Both are a warning that the universe presents deeper issues than we ever realized. That to me is the lesson of the black hole. Alas, I can say no more. I feel myself being carried away, not to return for another hundred years. But let me leave you hope for the work of all your colleagues. "All of

> these endeavors are based on the belief that existence should have a completely harmonious structure. Today we have less ground than ever before for allowing ourselves to be forced away from this wonderful belief.

It is very difficult to read these words without visualizing a mentor encouraging a mentee to press on.

The mentor-mentee relationship also surfaces in events surrounding Wheeler's first paper on geons.[252] In the fall of 1954, Wheeler sent a copy of his paper to Einstein. A relatively long interval passed before Einstein contacted Wheeler and suggested that they discuss the paper orally. Wheeler recalls that Einstein had considered the concept of a geon, but that he had concluded it was not important since "he saw no link with anything in nature." Moreover, Wheeler continues, " With his usual astonishing intuition, Einstein said in this conversation that he was prepared to admit that his equations of relativity allowed for geon solutions of the kind I was exploring, but he doubted the stability of a geon"—a conclusion Wheeler independently proved a few years later.[253]

For the purpose of this project, the details of Wheeler's paper are less important than the nature of the interaction. Here again, interplay of Wheeler and Einstein is very similar to that of a younger scholar working (albeit very independently) with an older mentor. As noted above, there is far more to

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[252] Wheeler and Ford, *Geons,* 236. Wheeler defines a 'geon' as a "hypothetical entity, a gravitating body made entirely of electromagnetic fields." The name is derived from (g for "gravity," e for "electromagnetism," and on as the word root for "particle." Hence geon.
[253] Wheeler and Ford, *Geons,* 238.

mentoring than parenting a dissertation. At the time of the geons consultation, Wheeler was forty-three years old. Einstein was seventy-five. In light of the foregoing and, given John Wheeler's quarter century commitment to general relativity, it seems clear that, at least in a virtual sense, Albert Einstein served as a mentor for John Wheeler.

Section 2.7 Review

So, what has been learned? First of all, it has been shown that many qualities that make for the character of an exceptional mentor were present in John Wheeler's youth. Certainly, he was a curious child and a precocious learner. This last is evidenced on numerous occasions in the preceding chapter. A prime example is the year in the one-room schoolhouse in Benson, Vermont, when John Wheeler completed the work of four academic years in one. Here, Wheeler learned (at least implicitly) that with motivated students, less direction is often more effective.

Other elements of character and a personality suited to mentoring surface sporadically in the narrative of Wheeler's life. From the beginning, John Wheeler was an independent thinker. Witness his choice to respect his parents' objections regarding the Pledge of Allegiance and then deciding that their convictions were not necessarily his. The anecdote about correcting the workmen in a ditch who were improperly connecting pipe demonstrates that Wheeler was always ready to look a situation over for himself—with 'fresh

eyes.' At Sunday dinners with his grandfather Archibald, Wheeler learned that there are always (at least) two sides to any proposition and, that a careful thinker will consider them all. From his teachers in Vermont and Youngstown, John Wheeler learned the importance of teachers who cultivate the learning habits and expand the curriculum of gifted students. More than anyone else, Joseph Wheeler taught his son the worth of work and the pride in a job well done. Finally, from his entire family—though most of all from his parents—John Wheeler learned the Joy of learning. So what did his mentors provide?

Wheeler has been asked more than once to compare Gregory Breit's approach to physics with that of Niels Bohr. There is no point in reciting that answer here. A better question might be, “What did you, both as a physicist and mentor, take from your experience with these mentors?” The most compelling clue is contained in Wheeler's reflections on the first published paper for which he was the sole author. For the convenience of the reader, the salient section of the block quotation has been re-posted here:

> As I look back now at that paper written when I was a twenty-one-year-old student, I am startled to find in it approaches to physics that have appeared again and again in my work throughout the rest of my career. First is my way of tackling problems (the practical doer in me). Second is my way of thinking about nature (the dreamer and searcher in me). I fearlessly jumped into mathematical analysis -and surely must have had to learn much of the needed mathematics as I went along. Equally fearlessly, I jumped into numerical calculation.[254]

[254] J. A. Wheeler, “Theory of the Dispersion and Absorption of Helium,” *Physical Review* 43 (1933), 258-263.

It is useful to keep in mind that this paper was written before Wheeler had extensive contact with either Breit or Bohr.

Here it is interesting to see how Wheeler refers to the way he tackles problems as being “a doer.” This approach is very much in the spirit of Breit. However, in the very next line Wheeler refers to himself as a “dreamer and a searcher.” This sentiment is very much in the spirit of Bohr. Finally there is the confidence (or perhaps faith) that a solution exists for every problem—a notion which was very congenial to Herzfeld and Einstein.

Plainly, there is more to the story of Wheeler's success as a mentor than his experience as an apprentice to Herzfeld, Breit, Bohr, and his quasi-apprenticeship with Einstein. John Wheeler came from a family that emphasized the importance of acquiring knowledge, inculcated a robust work ethic, and encouraged independent thinking. A number of adults including extended family and teachers reinforced these values. Still, Wheeler's professional skills, standards, and philosophy were not products of his youth; they were the result of a process of professional development that, according to science historian Frederic Holmes, takes an average of ten years.[255]

Frederic Holmes and others have reported the conventional wisdom of twentieth century scientists that “the most effective way to win a Nobel Prize is

[255] Frederic Lawrence Holmes, *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists* (New Haven, CN: Yale University Press, 200), xix [introduction].

to be trained by a Nobel Prize winner."[256] Likewise, it seems reasonable that skillful mentors quite often served as apprentices to other skillful mentors. Such groupings form a master-apprentice chain of wisdom that may well stretch over multiple generations of science.

So, what is the single most important thing that Wheeler took from his mentors? The answer is nurture. Consider the analogy of a track coach. The finest track coach on the planet cannot teach a slow runner to run fast. At best that coach will be able to help a slow runner become less slow. The same is true of mentors.

There are certain qualities which, taken together, characterize most successful scientists. These include academic talent, independent and careful thinking, a robust work ethic or even taking joy of learning almost anything. None of these elements are 'teachable' in the standard sense of the word. A skillful mentor who can recognize the potential in a young scientist has the opportunity to nurture that nascent talent into full bloom.[257] Therefore, in analyzing the qualities that established John Wheeler as a skillful mentor, a useful approach has been to look upstream for the professional practices, standards, and philosophy that Wheeler's mentors were most likely to inculcate in him.

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[256] Holmes, *Investigative Pathways,* 28; others who observe this tendency include Harriet Zuckerman, *Scientific Elite,* 99-100 and tables on 101-103; Kanigel, *Apprentice to Genius,* xiv [introduction] and elsewhere.
[257] Zuckerman, *Scientific Elite,* 110-112.

This chapter has shown how, in John Wheeler's early years, the personal qualities of a mature scientific mentor were developing. The next chapter deals with Wheeler's ability to nurture the potential in succeeding generations of scholars.

Chapter Three: Mentoring in Modern Physics: John Archibald Wheeler as Mentor

Section 3.1 Overview

At Waterloo University, in Ontario, Canada, former Wheeler student Kip Thorne delivered a lecture during the opening session of the Eighth International Congress on General Relativity and Gravitation. The date was Thursday, 11 August, 1977. At the close of Thorne's talk, another former Wheeler student, University of Maryland physicist Charles Misner, approached the podium. There, Misner presented John Archibald Wheeler with the commemorative volume, *Family Gathering*.[258] In his remarks, Misner explained that the aim of the project's initiator (who chose to remain anonymous) was to present John Wheeler with a collection of personal letters that, "could show in practice some of the workings of the apprenticeship system by which research attitudes and methods are passed on."[259] Professor Misner went on to quote the *Family Gathering* letter from Kenneth W. Ford:

> In John Wheeler's own professional development, the influence of Niels Bohr was deep and lasting. John, in turn, has had a profound influence on the style as well as the achievement of a large number of people who worked with him. I and many others, in our turn, have transmitted some part of this legacy to our students. There is an army of physics students in the United States whose view of nature and whose view of physics is more

[258] The full title is *Family Gathering: Students and Collaborators of John Archibald Wheeler gather some recollections of their work with him and of his Influence on them and through them on their own students. Assembled with the best wishes as John moves on to his new career in Texas.*
[259] *Family Gathering,* 1977, n.p.

> powerfully colored by the personalities and intellects of Niels Bohr and John Wheeler than they know. Like the oral traditions that dominate some Indian tribes, powerful threads of influence run through generations of scientists. John Wheeler is one of the "medicine men."[260]

For Charles Misner, Ken Ford and others, John Wheeler was far more than a mere teacher; he was part of a 'chain of wisdom' that stretched back to (and perhaps through) Niels Bohr.

This sense of Bohr's influence on John Wheeler is echoed by the physicist Jeremy Bernstein who observes, "Every scientist—Einstein being a notable exception—can find in his or her career a decisive teacher. For Bohr it was Ernest Rutherford. For Feynman it was Wheeler, and for Wheeler it was Bohr." James Gleick, biographer of former Wheeler student and Nobelist Richard Feynman (1918 – 1988) , described John Wheeler as the "apostle of Niels Bohr."[261]

Notwithstanding the analysis of former students such as Misner, and observers such as Bernstein and Gleick, Bohr is only part of the story. As the previous chapter has shown, several factors shaped John Wheeler's career—both as a physicist and as a mentor. In addition to Bohr, Gregory Breit provided Wheeler with an important complementary model for doing theoretical physics during his apprenticeship. Karl Herzfeld is a third

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[260] *Family Gathering,* 1977, n.p.
[261] Jeremy Bernstein, *Quantum Profiles* (Princeton, NJ: Princeton University Press, 1991), 107; James Gleick, *Genius: The Life and Science of Richard Feynman* (New York: Vintage Books, 1992), 93.

apprenticeship mentor whose influence on Wheeler's career is perhaps more visible in retrospect, but in any case, must not be discounted.[262]

In fact, Wheeler felt privileged to have studied under all three men. Of Herzfeld, Wheeler wrote: “No one who came so early from Europe to America continued longer to give so richly to this country out of the great European tradition of theoretical physics.” Wheeler concluded the obituary of his former dissertation advisor by observing:

> In saying farewell to a man of great human warmth, one who deeply cared, one treasures all the more his contributions to kinetic theory, statistical mechanics, and the structure of matter—and the high human standard he made for what it is to be a physicist.[263]

In light of this eulogy, and keeping in mind the discussion of Herzfeld in Chapter 2, any investigation of John Wheeler's interactions with students must certainly take into account the influence of Karl Herzfeld.

Similarly, John Wheeler's experience as Gregory Breit’s apprentice had an impact on the way Wheeler interacted with his students. It is also quite possible that Wheeler's experience with Breit taught him how NOT to behave with colleagues. At the outset of World War II, Wheeler suffered an unpleasant interaction with his former mentor in regard to Breit’s proposed moratorium on

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[262] Wheeler and Ford, *Geons,*107. When Wheeler was considering his choices for post-doctoral work after leaving Hopkins, Herzfeld told Wheeler that Breit “would be right” for him.

[263] John Archibald Wheeler, “Karl Herzfeld” [Obituary], *Physics Today,* 32, no.1 (Jan 1979): 99; The first statement was also quoted in Joseph F. Mulligan, “Karl Ferdinand Herzfeld, February 24, 1892 — June 3, 1978,” *Biographical Memoirs*, National Academy of Sciences, http://newton.nap.edu/html/biomems/kherzfeld.html (20 Mar 06) n.p.

the publication of studies in nuclear physics. Although Wheeler claims (at least as a student) not to have seen the confrontational side of Breit, he was well aware that Breit's relationships with his colleagues were often "prickly."[264] Still, Wheeler remained one of Breit's admirers. The reader may also recall from Chapter 2 that at a May 1977 symposium (less than three months before Wheeler was honored in Ontario) he described Breit by observing: "Insufficiently appreciated in the 1930s, he [Breit] is today the most unappreciated physicist in America."[265] In an interview with Charles Weiner and Gloria Lubkin, Wheeler was asked to compare the relative influence on his career of Breit (who tended to focus on the elements of a theory that can be calculated immediately) and Bohr (who tended to emphasize a broader, more schematic perspective), Wheeler responded, "I don't think one can get along without both. Bohr certainly would never have proposed to get along without it [Breit's approach]. He was most conscious of these checks, but content to let other people make them."[266] Some years later, Wheeler reiterated the

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[264] The work "prickly" occurs in Wheeler and Ford, *Geons,* 107; See also Wheeler interview with Ford, 03 Jan 1994, transcript, 502, 505-506.
[265] John Archibald Wheeler, "Some Men and Moments in the History of Nuclear Physics: The Interplay of Colleagues and Motivations," in *Nuclear Physics in Retrospect: Proceedings of a Symposium on the 1930's* ed. Roger H. Stuewer (Minneapolis, MN: University of Minnesota Press, 1979): 217-284, 234; Wheeler's statement is also quoted in McAllister Hull, "Gregory Breit: July 14, 1899 – September 11, 1981," National Academy of Sciences, *Biographical Memoirs*, Vol 74, 1998, http://www.nap.edu/html/biomems/gbreit.html (08 Dec 2003), n.p., also in National Academy of Sciences*, Biographical Memoirs* Vol 74 (Washington DC: National Academies Press, 1998) 26-57.
[266] Wheeler interview with Weiner and Lubkin, 05 Apr 1967, transcript, 17.

importance of Breit to his career. “I don’t think I could have built a better base for a career in theoretical physics,” Wheeler noted, “than I did at New York University with Breit, and at the University Institute for Theoretical Physics in Copenhagen with Bohr.”[267]

Nonetheless, among Wheeler intimates, there is a pervasive perception of Wheeler as the intellectual progeny of Bohr and Bohr alone. Prior to co-authoring the Wheeler autobiography *Geons*, Ken Ford conducted an extensive series of interviews with John Wheeler. In one of the later taped interview sessions (session ten of twelve), Ford asked a question about Niels Bohr.[268] The wording of that question indicates the extent to which many view Wheeler almost exclusively in terms of Bohr's mentorship to the exclusion of Breit and Herzfeld:

> It is often said that your style, your approach to physics, even some of your mannerisms, are derived from Bohr. Do you agree with this assessment? In what ways did your postdoctoral year with Bohr change you as a person and/or as a physicist? Was Bohr’s influence a factor much later when you had the courage to tackle fundamental puzzles of the quantum and its relation to the universe?[269]

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[267] Wheeler and Ford, *Geons,* 103.
[268] Wheeler interview with Ford (transcript), Princeton, NJ, 06 De 1993 – 12 Apr 1995; the first twelve sessions were tape recorded and transcribed; the last “tapes” (05 Oct 1994 – 12 Apr 1995) are remarks transcribed directly from dictation, after the writing of *Geons* had commenced. This particular interview was conducted on 15 Mar 1994 in Wheeler's office (in Jadwin Hall) at Princeton University.
[269] Wheeler interview with Ken Ford (15 Mar 1994), 1803.

It is interesting to note that at no point in the twelve sessions (conducted over several months) did Ford ask a similar question about Wheeler's relationship with either Gregory Breit or Karl Herzfeld.

Wheeler's response to Ford's question is as informative for what he does not say as it is for what he does:

> In what way did my postdoctoral year with Bohr change me as a person or as a physicist or both? I can remember what an inferiority complex I felt as colleagues at the Institute would sit around talking in German or Danish and me having trouble just keeping up with what they were saying, let alone trying to say anything myself ... It was a great encouragement to know James Franck. He was a marvelous people person ...
>
> One of the features about life in Copenhagen, [with] Bohr, Franck and others, [was] the willingness to discuss questions all over the map—politics, business, what-not. The feeling that it was all part of the scene that went on to take an interest in.
>
> I can recall Bohr taking the better part of the summer to write an obituary of Rutherford. He had such an admiration for Rutherford that he wanted to do it right. He had a special responsibility in Denmark, because he occupied the House of Honor. In that status, he was supposed to stand up for learning and matters of principle. It's almost like being named Archbishop, I suppose, except dealing with a wider range of issues. He and his wife, for example, spent quite a little effort in looking after the students in the field of art to give them encouragement, afternoon teas from time to time. The courage to tackle fundamental puzzles of the quantum and its relation to the universe.
>
> Courage is one word, but another word that might be more accurate would be desperation. That is some way to get through. Some day things will look so much simpler than they do today, and a desperate search to find a way through to that later day.[270]

[270] Wheeler interview with Ford (15 Mar 1994), 1804-1805.

While Wheeler humbly speaks of his “desperation” to arrive at a more comprehensive understanding of physics, there is no mention of Bohr's influence on the way that he (Wheeler) did physics.

It appears that John Wheeler very much preferred to see himself as his own man and distinct from the intellectual shadow of Bohr. This point comes through clearly in a 1988 interview with the historian and director of the Niels Bohr archive, Finn Aaserud. The discussion takes place in the context of Aaserud's asking about Wheeler's working relationship with Bohr during the 1939 nuclear fission paper in contrast with their working relationship when Wheeler was first in Copenhagen:

> **[Aaserud]** But he must have been very difficult to work with. I mean, he was all-consuming in some sense. I spoke for example to Weisskopf about it [Victor Weisskopf, 1908 – 2002]. Of course he loves Bohr, but also I got the impression that he could only be there for a little because, you know, it takes your own independence out of you, because it's so demanding and you become a part of Bohr in the discussion process, in a way. I don't know if that's the way he put it, but isn't that true? Or do you think that you could work as equals?
>
> **[Wheeler]** Well, I can recall, in the paper on nuclear fission, the formula for example for the rate of fission. I came with that to Bohr, and I had to argue it and persuade, but he accepted it. But he wouldn't take anything just on somebody's say so. He wanted to understand it through and through.
>
> **[Aaserud]** Was that different by virtue of your being at Princeton then? I mean, then you were more equals?
>
> **[Wheeler]** Yes. Perhaps so.
>
> **[Aaserud]** I mean, the visitors at the Bohr Institute had a very different role, of course, and I don't know if Bohr saw himself

> more as a mentor for them, than with you in Princeton at that time.
>
> **[Wheeler]** It's odd, I never thought of him as a mentor at all.
>
> **[Aaserud]** No?
>
> **[Wheeler]** No. I thought of our not facing each other, but facing a common difficulty, to try to understand something. And I'm not sure that it would have made any difference to be in Copenhagen. Well, after all, the paper on the collective model of the nucleus, which eventually just David Hill and I published, we worked out ... [The interview was interrupted by a telephone call; when the discussion resumes, the subject has changed.][271]

Still, Wheeler's assertion of intellectual parity with Bohr needs to be taken in context. It may be recalled from Chapter One that, in his 1998 autobiography (published ten years after the Aaserud interview), Wheeler himself described Bohr as a mentor: “What does a young researcher need at the beginning of a career? Perhaps, most of all, a good mentor.” Wheeler concluded this passage by noting “In two postdoctoral years, I was blessed with two wonderfully strong mentors, Gregory Breit and Niels Bohr.”[272]

So, what can be discerned in these evidently disparate narratives? Kenneth Ford, co-author of Wheeler's autobiography, notes that:

> By any external measure, Wheeler is a very modest man. If asked whether he is in the same league as Bohr and Einstein, he would surely laugh and say, 'Of course not.' Yet, deep down,

[271] John Archibald Wheeler, “Wheeler, John Archibald 1911 – 2008”, interview by Finn Aaserud, 04 May 1988, Princeton, NJ, unpaginated transcript, NBL-AIP, call number, OH30194.
[272] Wheeler with Ford, *Geons,* 103; Wheeler also refers to Bohr as his mentor on page 91.

> Wheeler has a sense of his own stature and, in my opinion, does see himself as in the same league as Bohr and Einstein.[273]

Nonetheless, Ford continues, “Wheeler revered Bohr.” It is also worth noting here that Bohr's portrait hung in Wheeler's office in Jadwin Hall until after Wheeler’s death.[274]

It appears that Wheeler was torn between a need for recognition of his own physics oeuvre and his deep veneration for Bohr. This is not an unusual circumstance in science. As the historian Frederic L. Holmes has noted, the transition from apprentice to independent scientist is a very complex process.[275] To the case in point; for Wheeler to distinguish himself from the historical shadow of a giant such as Bohr was a difficult prospect at best. Here it is useful to consider the phrasing of Aaserud's question, specifically his reportage of Victor Weisskopf's experience: working with Bohr could be “all-consuming” in the sense that it “takes your own independence out of you, because it's so demanding and you become a part of Bohr in the discussion process.”[276] Weisskopf’s concerns about working with Bohr were familiar to Wheeler. In *Geons*, he writes:

> The plan [for a 1949 Guggenheim Fellowship] included the proposition that I spend the year in Paris, with side trips to Copenhagen. Although I wanted to work with Bohr, I did not want to get back fully into the conversational culture of his institute. I

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[273] Kenneth W. Ford, letter to author (02 May 2006). Included in the letter was a photograph of Wheeler with busts of Einstein and Bohr. Ford reports that this photo was taken by him at Wheeler’s request.
[274] Based on the author’s visit to Wheeler’s office, 24 Apr 2008.
[275] Holmes, *Investigative Pathways,* 42
[276] Wheeler interview with Aaserud (04 May 1988).

> wanted time for isolated thinking and calculating, and knew that it would be an easy matter to travel by train from Paris to Copenhagen as often as I wished during the year.[277]

It would seem that Wheeler's nonchalance in the Aaserud interview notwithstanding, working with Bohr was, for Wheeler, something of a mixed blessing.

Wheeler's connection with Bohr stands in contrast to his relationship with Gregory Breit. Like Bohr, Wheeler has also described Breit as a mentor who was crucial to his career and yet, unlike the relationship with Niels Bohr, Wheeler never seemed compelled to make a declaration of independence from Breit.

In light of the foregoing, several questions emerge. Given the complexity of Wheeler's relationship with Bohr, how did Wheeler see himself in relation to his own students? How did Wheeler's students see themselves in relation to him? What aspects of the pedagogies employed by Herzfeld, Breit, and-or Bohr, did Wheeler incorporate into his own style? For that matter, were there aspects of Wheeler's style of doing physics that Wheeler's former students transmitted to their intellectual progeny? If so, what were they? Finally, as their own research and mentoring careers wind down, have the assessments of Wheeler's students changed between 1977 and 2009, and If so, how?

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[277] Wheeler and Ford, *Geons,* 183

With an eye to these questions, this chapter will focus on the qualitative aspects of John Wheeler's mentoring relationships with his students. This dissertation builds on, and differs from, a previous Master's Thesis in three significant ways. First of all, whereas the Master's Thesis relied primarily on letters to Wheeler by the contributors to *Family Gathering*, and more recent recollections of former students and colleagues obtained through electronic correspondence and personal communications with the author, this chapter benefits from having had access to archival materials including John Wheeler's research notebooks, and especially the 944 Ph.D. dissertations that were submitted to the respective departments of physics during Wheeler's years at Princeton and the University of Texas. Secondly, while at Princeton and Texas, the author had the opportunity to directly communicate with colleagues who knew Wheeler as an active faculty member (e.g. Val Fitch at Princeton and Richard Matzner at Texas); as well as those who knew him primarily as an emeritus (e.g. Dan Marlow at Princeton); and colleagues who, though working in the same fields, were outside Wheeler's 'sphere of influence' (e.g. Steven Weinberg at Texas). Finally, this dissertation benefited from the author having the opportunity to actually hear taped interviews with Wheeler's former students and colleagues, in addition to examining the transcripts of those interviews.

The aspiration of this chapter is to see John Wheeler from the perspective of his apprentices as well as his colleagues. In parallel, the

chapter will review Wheeler's assessment of the mentoring styles of Herzfeld, Breit, and Bohr. The overriding question here is, are there aspects of doing theoretical physics that John Wheeler acquired from his mentors and unconsciously or consciously transmitted to (or nurtured in) his apprentices, and if so, what are they?

The main focus of this study is on John Wheeler's Ph.D. students. This emphasis should not imply however, that Wheeler directed all his pedagogical energy toward doctoral students. Given the institutions in which he was employed, one might expect that a non-trivial number of the Wheeler academic family to be post-doctoral fellows. There is no reason to suppose that John Wheeler would have had less contact or put less effort into mentoring this population than he did for his Ph.D. students. Unfortunately, this group was very poorly documented. With the exception of anecdotal evidence here and there, the number and identities of Wheeler post-docs are absent from the historical record.[278]

[278] Neither Princeton nor the University of Texas had—or has—in place a systematic means of tracking post-doctoral fellows and the professors that they are committed to work with. I suspect this situation exists because in many, if not most cases, the funding for post-doctoral fellowships is external to the university (e.g. the National Science Foundation). Of course, in the modern era, even external funding is channeled through a university's Sponsored Research Office rather than the department of physics. It is not clear however, that in the time-frame in question, those funds were processed in a standardized manner. In any event neither the physics department at Princeton or the University of Texas seemed to be able to unambiguously indentify the mentors of individual post-doctoral fellows.

Then too, there are the undergraduate Junior Projects and Senior Theses that are required of physics majors at Princeton (the University of Texas has no such requirement). In fact, a number of former Princeton undergraduate students were among the contributors to *Family Gathering*. As might be expected in a festschrift, many of these letters contain moving expressions of gratitude for the inspiration, insight, and guidance they had received from Wheeler.[279] There are also, however, a number of instances in which Wheeler is profusely thanked in the acknowledgement section of dissertations and theses. Given the typically pro-forma nature of academic acknowledgements in that era (e.g. 'I want to thank Professor Dutton for suggesting this problem and his continued advice throughout.'), this particular well-spring of affection is noteworthy. So, what qualities set Wheeler apart from other professors?

For one thing, there was Wheeler's willingness to involve himself with junior scholars. A careful inspection of the advising assignments for Senior Theses (no record of advising was kept for the Junior Projects), reveals that this duty was almost always taken up by junior faculty members. Unlike most senior faculty, Wheeler welcomed the opportunity to work with younger students. He supervised at least twice as many Senior Theses as did any of his colleagues at Princeton and more Master's Theses than all but three of his

[279] *Family Gathering,* James B. Hartle, 206; R. Bruce Partridge, 236; Anthony Zee, 331; Adam Burrows, 464; Gary Horowitz, 486.

colleagues at Texas. In fact, when one correlates the Senior Thesis advising data from Appendix E (page 698), with the listing of faculty found in the Princeton University Catalogues, we find that Professor Thomas R. Carver (twenty-one Senior Theses advised; second only to John Wheeler) supervised only three Senior Theses after he became a full professor, whereas John Wheeler supervised all but three of the forty-three Senior Theses that list him as the advisor after he became a full professor. It should also be noted that Wheeler continued advising Princeton seniors even after his return from Texas in 1987.[280] Indeed, John Wheeler has famously proclaimed, “We all know that the real reason universities have students is in order to educate the professors.”[281]

Moreover, there are numerous people whom Wheeler significantly influenced despite the fact the there was comparatively little individual interaction. On 25 March 2008, shortly before his death on 13 April 2008, Wheeler received a letter from Professor Adam Burrows of Princeton. In the opening lines of his letter, Burrows noted that he had merely been an undergraduate student in three courses taught by Wheeler. Nonetheless,

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[280] Wheeler and Ford, *Geons,* 239; Wheeler Interview with Ken Ford, Meadow Lakes, NJ (24 Mar – May 1995), 2402; Princeton University, “Daniel E. Holz,” Princeton University Senior Thesis Full Record, http://libweb5.princeton.edu/theses/thesesid.asp?ID=79257 (03 May 2006).

[281] John Archibald Wheeler, interview with Jiří Bičák*. Czechoslovak Journal of Physics A*, Czech translation published in: *Československý časopis pro fyziku A* 28 (1978), 364-374; *Kosmické rozhledy* 2 (1979). The Polish translation published in: *Postepy fizyky* 29 (1978), 523-534. I am indebted to Ken Ford for alerting me to this quotation. See also Wheeler and Ford, *Geons,* 150.

Wheeler's enthusiasm for the subject at hand was contagious enough for Burrows to catch the bug:

> So, I have come full circle back to Princeton University … I am writing this letter to thank you for the inspiration you provided me during my salad days, for the stimulating courses you taught, for your generous mentorship, and for the glimpse you provided me of Physics at its best. I have often thought over the years about your role in sparking my interest in gravitation in particular, but astrophysics in general, and wanted to send you this modest note of gratitude upon my return to Old Nassau.[282]

In fact, Burrows was but one of several former Wheeler students who eventually became one of his colleagues.

Though seemingly always pressed for time, John Wheeler did not limit himself to helping future scientists. Carl S. Rapp, whose Senior Thesis was submitted to the Department of Politics, acknowledged Wheeler's assistance: "I am especially grateful for the aid and counseling offered me by Professor John Wheeler of the Princeton Department of Physics, whose sound advice has been invaluable in the writing of this paper."[283] Brit Katzen, who submitted a Senior Thesis to the Department of History in 1998, closed her

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[282] Letter, Adam Burrows to John A. Wheeler, 19 March 2008; quoted by permission.

[283] Carl S. Rapp, "A Study of the Modern Concept of Limited Warfare," Senior Thesis [Department of Politics], Princeton University, 1959, iii. Note: No other individual is acknowledged in Rapp's thesis and the online database of Senior Theses maintained by Princeton [http://libweb5.princeton.edu/theses/theses.asp (05 Nov 2008)] lists the advisor for Rapp's thesis as "not available. Also, this thesis was found in Box 29, Folder [bound] Defense Studies, 1958-1960, JAW-UT.

acknowledgements with this: “Finally Professor Wheeler, thanks for all the walks. You’re what made Princeton great for me.”[284]

More to the point, as a consequence of their advising relationships with John Wheeler, many of the young physicists went on to establish long-term, collaborative relationships with other Wheeler ‘progeny’ regardless of differences in age or stage of careers. In part this may be due to Wheeler assisting these students in choosing subjects that were both significant and doable within the one to two semester timeframe available to undergraduates. Wheeler, for one, was very proud of the results. “I have supervised many a senior thesis in my years at Princeton”, he remarked, “and some of them rate in quality and significance with Ph.D. dissertations.”[285] Wheeler’s enthusiasm notwithstanding, a more measured evaluation the quality of the work found in Senior Theses comes from Professor Dan Marlow, Chair, Department of Physics, Princeton University. Marlow observes:

> There is a lot of hype on that subject. The problem is that a grade on a Senior Thesis is viewed by some as a grade on the advisor as well as the student. Therefore, there is a natural bias toward seeing these theses in the most favorable light. Yes, we get some kids here that are ‘off-the-scale’ bright and who, by

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[284] Brit B. Katzen, “The Search for Pregeometry: The Work of John Archibald Wheeler” (Senior Thesis, Princeton University, 1998), 60, PRIN. Used by permission of the Princeton University Library.

[285] *Family Gathering,* examples include James B. Hartle, 206; David H. Sharp, 213; R. Bruce Partridge, 236; Anthony Zee, 331; Gary Horowitz, 486. For an example of a significant but doable project, see Daniel Holz, “Primal Chaos Black Holes” (Senior Thesis, Princeton University, 1992), PRIN. Used by permission of the Princeton University Library. Wheeler’s praise of Senior Theses is found in, Wheeler and Ford, *Geons,* 150.

> their senior year, are capable of work that merits publication. Even so, while most students are highly capable, they are generally not at the level of professional researchers during their undergraduate years. We might have one, or very rarely, two such students in a given year and none the next. It is by no means correct to say that a majority or even a substantial percentage of our senior theses merit publication.

Those caveats aside, Marlow continues:

> I would certainly not recommend doing away with the thesis and it's great that there are some that are of publication quality, since that no doubt inspires all students to aim high. [286]

On the face of it, Professor Marlow's contemporary assessment is undoubtedly more accurate than Wheeler's recollection. In fact, a casual survey of the publication record of Wheeler's former undergraduate students indicates that very few were published until they were in graduate school.

Then again, it seems that one of the implicit objectives of the Senior Theses is to build scholarly confidence. In that context, the percentage of theses that are "publishable" is less important than the percentage of students who believe they have the ability to become professional physicists. By that measure, judging by the contributions to *Family Gathering*, the statements of acknowledgement found in the Senior Theses, and more contemporary recollections of his students, Wheeler was successful in that part of the enterprise.

In addition to the Senior Theses, Princeton requires its physics majors to submit a Junior Paper, usually one that deals with a historical subject.

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[286] Personal communication with the author (09 Jan 2008, 06 Dec 2008), quoted by permission.

Unfortunately, unlike the Senior Theses, the Junior Papers and projects are not catalogued and retained in the archives. Consequently, there is no way to know how many of these projects and papers were supervised by John Wheeler, or how his input as an advisor was received. As with the post-doctoral students however, one occasionally encounters anecdotal evidence. Professor Daniel Kevles, renowned historian of science at Yale, recalls that John Wheeler was the advisor for his Princeton Junior Paper: “It was my first experience doing independent work on a theoretical project. Wheeler was generous with his time and encouraging with his criticism. I came away from the project with more confidence and fond memories of Wheeler.”[287]

Wheeler was also known to make himself readily available to assist students who were not his advisees. Indeed, Wheeler’s assistance and counsel were acknowledged in several dissertations for which he was not the advisor of record. Three examples come to mind: Paul Boynton, though not a Wheeler advisee, experienced John Wheeler as, “one of the most memorable and effective mentors I ever encountered. He has been an inspiration to me throughout my life, and not just my professional life.”[288] Boynton’s evaluation is also significant because after completing his doctorate, Boynton became a colleague of John Wheeler as a postdoctoral fellow at Princeton working under the supervision of Robert Dicke. Similarly, James Peebles and Curtis Callan,

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[287] Personal communication with author (09 May 2008), quoted by permission.
[288] Personal communication with author (20 Nov 2007), quoted by permission.

each of whom completed their dissertation under Professor Dicke's supervision, and each of whom went on to become colleagues of both Wheeler and Dicke, specifically acknowledged Wheeler's assistance (including "important discussions") in the completion of their respective dissertations.[289]

In any case, the remarks submitted by those individuals who obtained counsel and-or completed projects other than a Ph.D. under the supervision of John Wheeler are likely to enhance our comprehension of Wheeler as a mentor. Before proceeding however, it will be useful to explore a common theme in the *Family Gathering* letters to Wheeler and in subsequent interviews with Wheeler's former students—namely, his "lecture" style.

The term "lecture," as employed by Wheeler's students refers not only to the organization and delivery of prepared remarks, or the on-board problem solving sessions in which Wheeler 'collaborated' with his class, but also the inclusion of numerous detailed illustrations which provided a physical representation of the mathematical formalism describing a given

[289] See Philip James Edwin Peebles, "Observational Tests and Theoretical Problems Relating to the Conjecture that the Strength of Electromagnetic Interaction may be Variable" (Ph.D. diss., Princeton University, 1962), 104, PRIN. Used with Permission of the Princeton University Library. See also, Curtis Gove Callan, Jr., "Spherically Symmetr Cosmological Models" (Ph.D. diss., Princeton University, 1964), 69, PRIN. Used with Permission of the Princeton University Library. Note that in each case, the author's remarks strongly suggest that Professor Robert H. Dicke was the advisor of record. Note too, that both Peebles and Callan went on to become full professors in the Physics Department at Princeton.

phenomena.[290] Two classic Wheeler illustrations (shown below) come to mind immediately: 1) The famous capital “U” with an eye (looking to the right) symbolized the role of the observer-participant in physical phenomena; and 2) the two-dimensional radial coordinates collapsing along a third axis into a black hole was symbolic of the way, according to general relativity, that mass causes the curvature of space, which in turns, deflects the trajectory of mass (to quote Wheeler: “Spacetime tells matter how to move; matter tells spacetime how to curve.”)[291]

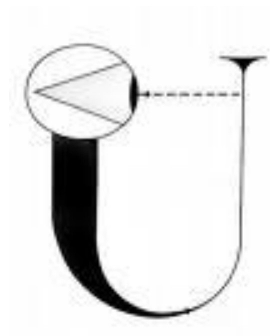

Figure 2-1. Wheeler’s depiction of the universe as a self-excited circuit: “Does looking back ‘now’ give reality to what happened then.” This notion builds on Bohr: “No elementary phenomenon is a phenomenon until it is a registered [observed] phenomenon.”

[290] See *Family Gathering,* Kenneth W. Ford, 84, where, in regard to Wheeler’s work in class, Ford remarks, “we learned physics by watching Wheeler learn.”
[291] Wheeler and Ford, *Geons,* 339, used by permission; Mirjana R. Gearhart, Forum: John A. Wheeler, “From Big Bang to Big Crunch,” *Cosmic Search Magazine* 1, no. 4 (1979) http://www.bigear.org/vol1no4/wheeler.htm (22 Oct 2003); Wheeler and Ford, *Geons,* 235.

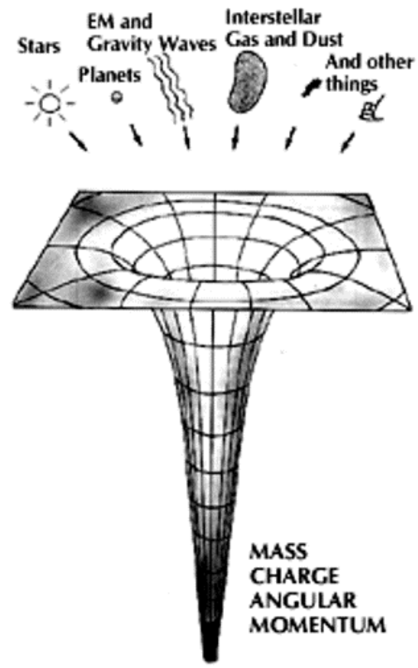

Figure 2-2. The curvature of Spacetime in the vicinity of a Black Hole and its resultant effect on the trajectory of matter.

Section 3.2 A Professor with an Anschaulich Perspective

As illustrated above, a frequent topic raised (and admired) by Wheeler's former students is his ability to make the physical quality of a phenomenon stand out from the mathematical formalism that describes it. This ability goes beyond the diagrams that accompanied Wheeler's lectures and informal discussions. A *Family Gathering* letter from Edward F. Redish, whose Princeton senior thesis was supervised by Wheeler, helps to frame this discussion. In regard to Wheeler's ‘lecture’ style, Redish wrote:

> [Y]ou have a particular style of thinking about problems in physics. Beneath whatever algebra represents a phenomenon,

> you always find the working-model; a real thing with nuts, bolts, and rust, with moving parts and real world limitations, and, above all, a picture that you can draw. You always showed a deep empathy for physical phenomena.
>
> This is a stylistic aspect of physics which didn't come naturally to me. Like many of my own students, I was more adept at manipulating equations than in extracting the "real physics." I have had to work hard to develop a physical empathy, but the struggle to do so has been rewarding and the results intensely satisfying.[292]

So, what does it mean to 'extract the real physics?'

The historian Arthur Miller has noted that visual representation has long been associated with science. In the case of Galileo Galilei (1564-1642), diagrams of his falling body experiments enabled him to show that weights fall at consistent rate of acceleration regardless of their horizontal motion. As proof of his hypothesis, Galileo developed a thought experiment; if a weight is dropped on the forward side of a ship's mast, the weight falls to the forward side of the mast's base—even if the ship is in motion (so long as the motion is uniform). From this thought experiment, Galileo demonstrated a *quality* of motion (i.e. vertical and horizontal movement are separate components of the total motion of a body).[293] Differential calculus, had it been available to Galileo, would have served to *quantify* the vertical motion of the falling body. In and of

[292] *Family Gathering,* Edward F. Redish, 270.
[293] Arthur I. Miller, "Image and Representation in Twentieth Century Physics," in *The Modern Physical and Mathematical Sciences,* ed. Mary Jo Nye, Vol. 5 of *The Cambridge History of Science,* General eds. David C. Lindberg and Ronald L. Numbers (New York: Cambridge University Press, 2003): 198-215, 191-194; See also James T. Cushing, *Philosophical Concepts in Physics: The Historical Relation between Philosophy and Scientific Theories* (Cambridge, UK: Cambridge University Press, 1998), 80, for Galileo's thought experiment.

itself, however, the calculus could not have provided a qualitative description of the fall, or for that matter, the mutual independence of horizontal and vertical motion.

In the wake of Isaac Newton (1642 – 1727) and Gottfried Leibniz (1646 – 1716), differential and integral calculus evolved into more sophisticated analytical tools through the advances of Leonhard Euler (1707 – 1813), Joseph-Louis Lagrange (1736 – 1813), Pierre Simon Laplace (1749 – 1824), Jean-Baptiste Fourier (1768 – 1830), and others. Concurrently, the physical phenomena that scientists were investigating became more complex. The qualitative analysis of Galileo's falling ball only involved the vertical dimension. Real world physics, however happens in three dimensions. As Ludwig Boltzmann (1844 – 1906) observed:

> Surfaces of the second order, represented by equations of the second degree between the rectangular co-ordinates of a point, are very simple to classify, and accordingly all their possible forms can easily be shown by a few models, which, however, become somewhat more intricate when lines of curvature, loxodromics and geodesic lines have to appear on their surfaces.[294] On the other hand, the multiplicity of surfaces of the third order is enormous, and to convey their fundamental types it

[294] A loxodromic line is equivalent to a rhumb line. Each makes the same angle with successive meridians of longitude regardless of the latitude at which they intersect. On a Mercator projection (also known as a loxodromic projection) a loxodromic or rhumb line is straight. However on the surface of a sphere (or an oblate spheroid) a loxodromic line is neither straight nor the shortest distance between two points. The contrast here is with a Great Circle which appears curved on a Mercator projection, but is in fact a straight line on the surface of a sphere.

> is necessary to employ numerous models of complicated, not to say hazardous construction.[295]

Since real-world models were so difficult to construct, physicists used common experiences and knowledge as metaphors. Such metaphors added a qualitative sense to the quantized understanding that emerged from analysis by differential equations. These metaphors also offered a way to visualize what cannot be seen.

For example, James Clerk Maxwell (1831 – 1879) developed a set of four differential equations that described the oscillating and reciprocating motion of electromagnetic fields. Nowhere in these equations is there the tiniest hint of a wave. Nonetheless, the metaphor of waves in water was employed to explain the interference, refraction and diffraction of light “waves.” It is important here to note the perceptional difference between the phenomenon of light and Galileo's falling weight. Many people, particularly in Galileo's day, have seen an object dropping from the mast of a ship; it was therefore a matter of common perception. On the other hand, no one has ever seen a light wave; it can be visualized, though not seen.

In his “Image and Representation in Twentieth Century Physics,” Arthur Miller employs the language of Immanuel Kant (1724 – 1804) and introduces the terms “*Anschaulichkeit*” and “*Anschauung.*” Anschaulichkeit, translated as visualizability, is used to describe a phenomenon that “is immediately given to

[295] Ludwig Boltzmann, “Model,” in *The Encyclopaedia Britannica*, 11th ed., Vol. 18 (New York: Encyclopaedia Britannica, 1911): 638-640, 638.

the perceptions or what is readily graspable in the Anschauung [visual perception]" (e.g. a weight falling from a ship's mast). Anschauung, translated by Miller as images of visualization, is more abstract, and in Kant's frame of reference, superior to the more concrete Anschaulichkeit. Anschauung can also be translated as "intuition." Intuition in this sense, Miller explains, "meant the intuition of phenomena that results from a combination of cognition and perception." From the related concepts of Anschaulichkeit and Anschauung, including the compound meaning of Anschauung, Miller coins the term "anschaulich," by which he means a concept that, in English, most nearly matches the word "intuitive." Miller continues, "Translating this formalism to the way in which scientists in the German-language milieu understood it is to say that the Anschauung of an object or phenomenon is obtained from a combination of cognition and mathematics."[296]

Of course, in the case of weights falling from a mast, there is no reason to distinguish between what one has seen and what is vizualizable; Anschaulichkeit and Anschauung are equivalent. In the case of quantum mechanics, the wave-particle duality of light, the physics of nucleons (particles that make up a nucleus), or even the mass-induced curvature of a four-dimensional space-time however, a perspective that involves what is

[296] Miller, "Image and Representation," 197.

anschaulich enables both a qualitative and quantitative assessment of a phenomenon.[297]

I would also point out that the development of an anschaulich perspective is not trivial; at some point in the process, the theoretician begins to get a sense of diminishing returns on his or her effort. Ergo, as quantum mechanics became more complex, it became increasing a matter of mathematical analysis. This is particularly evident in the work of Werner Heisenberg (1901 – 1976). By the late 1920s, there was a general retreat from incorporating physical representations into the discussion of quantum mechanics and an increased reliance on theoretical formalisms. The exception to this trend was Erwin Schrödinger (1887 – 1961) who promulgated his equation for quantum wave-mechanics in 1926. Even so, Schrödinger was aiming to eliminate the discontinuities in quantum theory rather than to bring graphical representation back into the practice of theoretical physics. Consequently, Schrödinger's fling with physicality did not stop the swing toward mathematical formalism. This is seen in the quantum electrodynamics work of Paul Adrien Maurice Dirac (1902 – 1984). Galileo's famous assertion, “the Grand book of the universe was written in the language of mathematics

[297] Miller, “Image and Representation,” 197-199.

…" seemed to be the guiding philosophy in the quantum physics community.[298]

During the 1930s and immediately following World War II, the hot topic within theoretical physics was quantum electrodynamics (QED). There were flaws in Dirac's early work (ca 1930) that needed to be addressed in order for the new sub-discipline of particle physics to move forward. The National Academy of Sciences organized a conference of the leading QED theorists, which was held on Shelter Island, New York in June of 1947. While some progress was shared, shortly after the Shelter Island meeting, there was a consensus among the participants that another conference would be useful. That conference, also organized and funded by the NAS, was held in the Pocono Mountains of Pennsylvania from 30 March through 2 April, 1948.[299] Mathematical formalism, in the manner of Julian Schwinger (1918 – 1994), dominated both conferences but especially the latter. In fact, at the 1948 Pocono conference, Richard Feynman utterly failed to communicate his

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[298] Galileo Galilei, *Il Saggiatore (The Assayer),* trans. George MacDonald Ross, 1998, Available online: <http://www.philosophy.leeds.ac.uk/GMR/hmp/texts/modern/galileo/assayer.html> (20 May 2005). The full quotation is: "Philosophy is written in this grand book the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and to read the alphabet in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures, without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth."

[299] Richard P. Feynman, "Pocono Conference," *Physics Today,* 1, no. 2 (Jun 1948): 8-10, 8.

analysis, in part because his graphical representation of path integrals (now known as Feynman Diagrams), completely alienated a number of the older physicists, including Niels Bohr.[300] At the time, there seemed to be no room for an anschaulich perspective in QED.

Nonetheless, from the first, John Wheeler, who attended both QED conferences, recognized that teaching subjects as complex as nuclear physics, quantum mechanics, or general relativity required him to provide an analysis from as many perspectives as possible. Wheeler evidently realized (as did Bohr in areas other than QED), that while mathematical formalisms of physical phenomena offer precise quantization, they are often qualitatively (i.e. physically) ambiguous. To rely exclusively on mathematical formalisms, even if students such as Redish were more accustomed to (or enamored with) an intensely mathematical methodology, was to do his students a disservice.

Karl Herzfeld was also a man who utilized an anschaulich perspective, and the next section will address the influence of Herzfeld in John Wheeler's mentoring style.

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[300] Gleick, *Genius,* 257-259; The alienation of Bohr is significant because Bohr had a well-known aversion to an over-reliance on mathematics in the explication of physical phenomena. For more on this see Abraham Pais, *Niels Bohr's Times in Physics, Philosophy, and Polity* (New York: Oxford University Press, 1991), 20, 178-179; See also Feynman, “Pocono Conference,” 10, Adding salt to the wound, Feynman was assigned the task of writing up John Wheeler's notes from the conference. The report on Schwinger's presentation occupied half a column. Feynman's presentation merited only five lines, beginning with the phrase, “There was also presented by Feynman ...”

Section 3.3 Wheeler as Mentor: The Influence of Herzfeld

As reported in Chapter 2, Wheeler observed, “Herzfeld had two religions, Catholicism and physics.”[301] That faith in physics was manifested in a fundamental presumption that the universe was comprehensible. This ‘faith’ in the comprehensibility of the universe is, of course, a ubiquitous and a long-standing characteristic among many theoretical physicists, with Albert Einstein foremost among them.

Einstein’s remark “*Raffiniert ist der Herr Gott, aber boshaft ist er nicht*.” Is well-known and is translated by Amir Aczel as: “Tricky (crafty, shrewd) is the Lord God, but malicious He is not.” In his book *The Shaky Game: Einstein, Realism, and the Quantum Theory*, the philosopher of science Arthur Fine discusses Einstein’s realism, coining the term “motivational realism.” Karen Merikangas Darling uses this term to discuss the faith in physics of the turn-of-the-twentieth-century theoretical physicist Pierre Duhem, who (like Herzfeld) was a practicing Catholic. For Duhem, all physicists take physical theory to be at least approximately true and, in Duhem’s view, physicists “simply cannot help but think that physical theory is a reflection of a real and logically unified ontological order.” Otherwise, they would have no motivation to continue their scientific quest.[302]

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[301] Wheeler and Ford, *Geons,* 98.
[302] Karen Merikangas Darling, “Motivational Realism: The Natural Classification for Pierre Duhem,” *Philosophy of Science*, 70 (Dec 2003), 1125-1136, esp. 1128, 1129-1131; Arthur Fine, *The Shaky Game: Einstein, Realism, and the Quantum Theory*, 2nd ed. (Chicago: University of Chicago

Here, it may be useful to recall Wheeler's obituary of Herzfeld in which Wheeler lauded Herzfeld's efforts "to make clear the structure and beauty of God's creation" and Wheeler's non-technical writing in which he repeatedly speaks of beautiful solutions or the beauty in nature.[303] By precept and example, Wheeler and Herzfeld demonstrated a deep and profound conviction regarding the ultimate clarity and comprehensive nature of physical law. We might call this attitude one of motivational realism, a simultaneously unprovable and irrefutable presupposition of a clear and cohesive explanation of natural phenomena. It is the "faith" in physics that Wheeler saw in Herzfeld. The next question is, to what extent did Wheeler inculcate this 'faith' in his apprentices? The following four narratives make the case:

William Wooters, a graduate student at Texas, describes how, during the preparation of his dissertation, John Wheeler instilled his conviction of a comprehensible universe:

> Professor Wheeler, having awakened my interest in the foundations of quantum mechanics, generously gave much of his valuable time to discuss with me the problems and prospects of

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Press, 1986); and, on Einstein's remark, Amir D. Aczel, *God's Equation: Einstein, Relativity, and the Expanding Universe* (New York: Four Walls Eight Windows, 1999), 13-14

303 Wheeler, "Karl Herzfeld" [Obituary], Physics Today 32, no.1 (Jan 1979), 99; Wheeler and Ford, Geons, 84, 148, 236, 355; See also, Wheeler interview with Weiner and Lubkin (05 April 1967), 9, 13, 24, 25, 26, 27; John Archibald Wheeler, "Some Men and Moments in the History of Nuclear Physics," 224, 226, 227, 250, 255, 260; Wheeler interview with Ford (15 Mar 1994), 1804-1805.

> physics at its most fundamental level, and transferred to me his belief that the hardest problems can yet be solved.[304]

Sometimes this insight came by way of a negative example.

Kip Thorne has written of his experience as Wheeler's graduate student and the first problem that John Wheeler assigned him in the Fall of 1962. The problem stemmed from a discovery by Wheeler's colleague Mael Melvin, then at Florida State University. The conventional thinking about magnetism was that magnetic field lines (one may recall here the grammar school experiment with iron filings on paper) are mutually repulsive and only held together by the metal bar that they pass through. As Thorne reports, Melvin had shown (using Einstein's field equation) that magnetic field lines can also be held together by gravity without the aid of any physical magnet. Melvin's reasoning was that magnetic field lines are a form of energy, and since energy is a form of mass, it gravitates. Wheeler believed that Melvin had overlooked an inherent instability and, “like a pencil balanced on its point,” any perturbation would cause the field lines to collapse—possibly into some sort of singularity (e.g. a miniature black hole).

The problem Wheeler assigned Thorne was to perform the calculations and see if his [Wheeler's] hunch could be verified. With this assignment from his brand new professor in hand, Thorne set to work:

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[304] William K. Wooters, “The Acquisition of Information from Quantum Measurements” (Ph.D. diss., University of Texas at Austin, 1980), iii. Note John Wheeler was not Wooter’s supervising professor of record.

> For many months I struggled with this problem. The scene of the daytime struggle was the attic of Palmer Physical Laboratory in Princeton, where I shared a huge office with other physics students and we shared our problems with each other, in a camaraderie of verbal give-and-take. The nighttime struggle was in the tiny apartment, in a converted World War II army barracks, where I lived with my wife, Linda (an artist and mathematics student), our baby daughter, Kares, and our huge collie dog, Prince. Each day I carried the problem back and forth with me between army barracks and laboratory attic. Every few days I collared Wheeler for advice. I beat at the problem with pencil and paper; I beat at it with numerical calculations on a computer; I beat at it in long arguments at the blackboard with my fellow students; and gradually the truth became clear. Einstein's equation, pummeled, manipulated, and distorted by my beatings, finally told me that Wheeler's guess was wrong. No matter how hard one might squeeze it, Melvin's cylindrical bundle of magnetic field lines will always spring back. Gravity can never overcome the field's repulsive pressure. There is no implosion.

Here, some students might well begin to feel some fear for their professional future; in his very first assignment in graduate school, Thorne had disappointed his professor by failing to prove the professor's new pet hypothesis. As we have seen however, for John Wheeler (again, as with Karl Herzfeld) the physics was sacred; it was far more important than any particular physicist's ego. This attitude is reflected in the reaction Thorne received when he presented Wheeler with the fruit of his labor:

> This was the best possible result, Wheeler explained to me enthusiastically: When a calculation confirms one's expectations, one merely firms up a bit one's intuitive understanding of the laws of physics. But when a calculation contradicts expectations, one is on the way toward new insight.[305]

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[305] Kip S. Thorne, *Black Holes and Time Warps: Einstein's Outrageous Legacy* (New York: W. W. Norton & Co., 1994), 262-265.

Obviously faith in an outcome is important. On the other hand, there has to be a practical means of applying this comprehensibility principle. After all, faith without works is nothing more than wishful thinking.

Peter Vajk, in acknowledging Wheeler's contribution to his dissertation, describes how Wheeler taught him to attack a difficult problem. Although the method incorporated an unyielding application of mathematical pressure, it nonetheless preserved the requisite agility to accommodate fresh approaches. Vajk writes:

> In large part, this thesis owes its general form to my advisor, Professor John A. Wheeler, who many years ago stimulated my interest in physics, especially general relativity. More recently, during the development of this thesis, he has taught me by example the value of asking, upon completing a calculation, 'To what question have I found the answer?' This process of self-interrogation was most valuable at those times (well-known to most graduate students) when I was faced with the quasi-existential dilemma, 'Where do I go from here?' During these sometimes protracted agonies, Dr. Wheeler's unlimited patience has also been most helpful.[306]

The patience that Vajk found so helpful could have, just as easily been characterized as faith—the now familiar philosophical grounding in the comprehensibility of the universe that so many students saw in Wheeler.

Brendan Godfrey, a Wheeler Ph.D. student (1970) and current (as of 2008) Director of the Air Force Office of Scientific Research, saw this aspect of Wheeler and articulated his perception of Wheeler's faith in *Family Gathering*:

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[306] J. Peter Vajk, "The Theory of Spherically Symmetric Spacetimes: A New Forumlation" (Ph.D. Dissertation, Princeton University, 1968), v, PRIN. Used by permission of the Princeton University Library.

"I am most struck by you not so much as a scientist, per se, but as a man of religion and philosophy, with a thirst for learning and a deep insight into history.[307]

In the narratives of Wooters, Thorne, Vajk, and Godfrey we have seen how Wheeler inculcated a deep and abiding faith in physics and the comprehensibility of the universe in his own mentees. We have also seen that origins of this faith in physics as a philosophy of science was most clearly articulated to Wheeler by his mentor Herzfeld (perhaps one should include Einstein here as well). As Wheeler said of Karl Herzfeld, "I'm immensely indebted to [Herzfeld] for his wonderful perspectives on physics."[308] But having physics as a religion goes beyond a simple faith in the ultimate solution of problems. Religious indoctrination includes standards of conduct. Here again we employ the narratives of Wheeler's students.

In his 1977 *Family Gathering* letter, Kip Thorne catalogued the most important things that he had learned from John Wheeler. First among these lessons was a tacitly communicated resolve to maintain rigorous scientific integrity:

> The most important thing that I learned from you, and have tried to pass on to my own students, is a <u>code of ethics for scientific research</u>: You never verbalized that code; rather, you instilled it in your students by your own example and by the advice you

[307] *Family Gathering,* 391; Air Force (U.S.), Office of Scientific Research, "Dr. Brendan B. Godfrey" [Biography], available online: <http://www.afosr.af.mil/pages/godfrey.htm> (16 Sep 2005).
[308] Wheeler interview with Ken Ford (20 Dec 1993), 408.

> gave when they faced decisions: Research should be a cooperative quest for truth, you implied; not a competitive quest for recognition and individual credit. When two groups have done similar work nearly simultaneously, they should try to publish jointly, taking the best from each effort and sharing the credit. [underlining in original][309]

Stated alternatively, the best lesson that Kip Thorne absorbed from John Wheeler was that the work of physics should be considered sacrosanct and beyond professional and/or personal envy. If, indeed, the work is sacrosanct, then the originator of the work is also deserving of one's respect, regardless of their race, age, gender, or station in life. Anything less than this level of integrity only serves to demean the profession. In this respect, John Wheeler again seems to have echoed the sentiments of Karl Herzfeld who, in Wheeler's own words, considered physics, "not a secular, but a religious calling."[310] Indeed, acting in the spirit of an apostle of physics, Herzfeld tirelessly encouraged women and minorities to undertake graduate study in physics throughout his tenure at Catholic University.[311] Karl Herzfeld also was

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[309] *Family Gathering,* Kip S. Thorne, 306.

[310] Wheeler, "Karl Herzfeld" [Obituary], Physics Today (Jan 1979), 99; see also, Mulligan, "Karl Ferdinand Herzfeld," n.p., The notion of science as a devotional calling is found in Max Weber's 1918 essay "Science as a Vocation," pp. 129-156 in H. H. Gerth and C. Wright Mills, trans. and ed., *From Max Weber: Essays in Sociology* (London: Routledge and Kegan Paul, 1948), 134.

[311] It is noteworthy that while he was a Catholic University, Herzfeld made an informal arrangement with the physics department of (largely black) Howard University to steer their best and brightest students toward graduate work at Catholic University, thereby offering black physics students an avenue to graduate education. Also, during Herzfeld's time at Catholic University (1936-1962) 85 Ph.D.s were awarded in physics; nearly 10% of these went to women—a huge percentage in that era.

responsible for John Wheeler's first direct experience with women in the discipline of physics when Herzfeld and Maria Goeppert-Mayer (1906 – 1972) jointly conducted a seminar on quantum physics at Johns Hopkins University.

Goeppert-Mayer became one of the most widely-recognized women in theoretical physics, sharing the 1963 Nobel Prize in Physics with Eugene Wigner and J. Hans D. Jensen. Her path had not been easy. Although Maria Goeppert's father was a professor of pediatrics at Göttingen, she nonetheless had to overcome numerous systematic obstacles and an imploding German economy just to gain admission to the university that employed her father. The Nobelist James Franck (1882 – 1964), later a mentor, and eventually a colleague at Johns Hopkins, was a family friend and neighbor, as was the renowned mathematician David Hilbert (1862 – 1943).[312] The mathematicians Richard Courant (1888 – 1972), Hermann Weyl (1885 – 1955), Gustav Herglotz (1881 – 1953) , and Edmund Landau (1877 – 1938) were members of the faculty in Göttingen's mathematics department and known to the Goeppert family. As might be expected, this collection of luminaries

[312] Robert G. Sachs, "Maria Goeppert-Mayer, 1906 – 1972," in National Academy of Sciences, *Biographical Memoirs*, Vol.50, n.p. http://www.physics.ucla.edu/~moszkows/mgm/rgsmgm4.htm, also in National Academy of Sciences. *Biographical Memoirs* Vol. 50 (Washington, DC: National Academies Press, 1979), 310-329: Maria Goeppert-Mayer, "Biography," http://nobelprize.org/nobel_prizes/physics/laureates/1963/mayer-bio.html (12 Feb 2009). Also in *Nobel Lectures, Physics 1963-1970* (Amsterdam: Elsevier Publishing Company, 1972), n.p.; James Franck, "Biography," http://nobelprize.org/nobel_prizes/physics/laureates/1925/franck-bio.html (16 Feb 2009), also in *Nobel Lectures, Physics 1922-1941* (Amsterdam: Elsevier Publishing Company, 1965), n.p.

precipitated a flow of talented students to and through Göttingen, and Maria Goeppert came to know many of them including Arthur Holly Compton (1892 – 1962), Max Delbrück (1906 – 1981), Paul A. M. Dirac (1902 – 1984) , Enrico Fermi (1901 – 1954), Werner Heisenberg (1901 – 1976), John von Neumann (1903 – 1957), J. Robert Oppenheimer (1904 – 1967), Wolfgang Pauli (1900 – 1958), Linus Pauling (1901 – 1994), Leo Szilard (1898 – 1964) , Edward Teller (1908 – 2003), and Victor Weisskopf (1908 – 2002).[313]

As a young woman, Maria Goeppert held a keen interest in mathematics, and in the Spring of 1924, she began her academic career at Göttingen as mathematics student. Later that year, Max Born invited her to join the Göttingen physics seminar. This was, of course, a time of great strides in quantum theory and Göttingen was then one of the epicenters of modern physics. Consequently, Maria Goeppert's strong mathematical background was well suited to the Göttingen physics program. In spite of Born's (and Goeppert's) predilection to mathematical formalism however, it is clear that, over time, Goeppert was also influenced by James Franck's nonmathematical approach to physics. Robert Sachs, Goeppert-Mayer's biographer, observes that, "a reading of her [Goeppert's] thesis reveals that Franck already had an influence at that stage of her work."[314]

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[313] Sachs, "Maria Goeppert-Mayer, 1906 – 1972," n.p.
[314] Sachs, "Maria Goeppert-Mayer, 1906 – 1972," n.p.

In 1929, Joseph E. Mayer, a young American chemist on a Rockefeller Fellowship, came to study with James Franck. He and Maria Goeppert struck up a fast friendship and they were married in 1930, after she had completed her Ph.D. The couple then headed to Baltimore where Joseph Mayer took up a position in the Department of Chemistry at Johns Hopkins University.[315]

Despite her obvious qualifications, including impressive work on the Fermi model of the atom, Goeppert-Mayer received no offer of regular employment at Johns Hopkins.[316] In 1935, Isaiah Bowman became president of Johns Hopkins and Maria Goppert-Mayer's prospects for permanent employment at Hopkins plummeted. John Wheeler and the physicist Joseph Mulligan (author of Karl Herzfeld's biography in the 2001 National Academy of Sciences *Biographical Memoirs*) each later observed that, “a negative attitude toward foreigners,” coupled with her gender, effectively eliminated any possibility that Maria Goeppert-Mayer could become part of Hopkins' regular faculty. Wheeler and Mulligan differed in that Mulligan tended to see this xenophobia and sexism as having originated within the physics department while Wheeler found fault more specifically with Bowman. In either case, as a

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[315] Bruno H. Zimm, “Joseph Edward Mayer (February 5, 1904 - October 15, 1983),” http://books.nap.edu/openbook.php?record_id=4548&page=210 (16 Feb 2009), 210-221, also in National Academy of Sciences, *Biographical Memoirs* V 65 (Washington, DC: National Academies Press, 1994), 214, 216.
[316] Wheeler interview with Ken Ford (06 Dec 1993-04 Feb 1994), 104, 908, discusses Herzfeld-Mayer seminar. Also in Wheeler and Ford, Geons, 97; Wheeler interview with Ford (03 Jan 1994), 605 discusses Mayer's work on the Fermi model of the atom. See also Mulligan, “Karl Ferdinand Herzfeld, February 24, 1892 — June 3, 1978” n.p.

consequence of these prejudices, Wheeler notes that Hopkins lost three first-rate scientists. Joseph Mayer and Maria Goeppert-Mayer went on to Columbia, then Chicago, and finally to UC San Diego where Maria Goeppert-Mayer was at long-last offered a tenured position. In addition, at least in part because he was unhappy about the Hopkins' unwillingness to employ Goeppert-Mayer, Herzfeld left Hopkins for Catholic University in Washington, DC in 1936. Herzfeld was still associated with Catholic University when he died in 1978. [317]

Like Herzfeld, Wheeler saw physics as a vocation or a calling that transcended racial, ethnic, or gender boundaries. As a case in point, Wheeler's very first Ph.D. student at the University of North Carolina was Katherine Way, who went on to a distinguished research career at the National Bureau of Standards. In *Geons,* as well as his interviews with Ken Ford, Wheeler describes Way as one of a "tiny handful" of women in physics in the 1930's. Although women physicists are "more numerous now," Wheeler asserted, "they still [Wheeler was speaking in the 1990s] are not nearly numerous enough." For Wheeler, the gender of Katherine Way was far less important than her contributions to the corpus of knowledge in physics. In fact,

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[317] See Joseph F. Mulligan, "Karl Ferdinand Herzfeld," n.p. With regard to Goeppert-Mayer and departmental dissension, Mulligan cites a 16 May 1936 letter from Herzfeld to his old professor Arnold Sommerfeld in Munich, Germany. This letter is in the Sommerfeld Archive at the Deutsches Museum in Munich; For John Wheeler's thoughts on Isaiah Bowman and the departure of Goeppert-Mayer, Mayer, and Herzfeld, see Wheeler interview with Ford (20 Dec 1993-04 Feb 1994), 406, 908; See also Wheeler and Ford, *Geons,* 97.

on three separate occasions in the interviews with Ken Ford, Wheeler recalled that Way had some important insights that, in retrospect, should have pointed him toward the mechanism of nuclear fission. Wheeler's final comment on Katherine Way speaks to his sense of collaboration with his students. Wheeler seems to recall thinking at the time (1937) that her thesis would offer him, "a wonderful opportunity for me to learn more nuclear physics."[318]

Moreover, even the most casual survey of the surnames on the letters incorporated into *Family Gathering* reveals a broad spectrum of ethnicity. While this level of ethnic inclusion is all but assumed in 2008, such was certainly not the case through much of John Wheeler's career. In 1936, for example, future Nobel Laureate Richard Feynman was not accepted into the undergraduate program at Columbia University because the university faculty already had its agreed-upon quota of Jews. Later, despite the fact that Feynman had been the best undergraduate that the MIT physics department had seen in years and despite his achieving a perfect score in the physics

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[318] Wheeler interview with Ken Ford (10 Jan 1994-10 Jan 1995), notes Katherine Way as his first Ph.D. student, 903, 1805, 2311; Ibid, 708, 902, 1004 notes that Katherine Way's work on physics of the nucleus adds insight that (in retrospect) pointed toward the mechanism of nuclear fission; Ibid, Wheeler notes that Way's dissertation gave him "an opportunity to learn more nuclear physics; Wheeler and Ford, *Geons,* 150 notes that Way was among a "tiny handful of women in physics at the time [1930s] and while there are more now [1990s] there still are not nearly enough;" See also Murray Martin, Norwood Gove, Ruth Gove, Subramanian Raman, and Eugene Merzbacher. "Katharine Way" [Obituary], *Physics Today* 49 no. 12 (Dec 1996): 75, Academic Search Premier http://0search.epnet.com.oasis.oregonstate.edu:80/login.aspx?direct=true&db=aph&an=9612171661 (13 Sep 2005).

section of the Graduate Record Exam, a veritable flurry of correspondence was required to get Feynman admitted to Princeton.

An exchange of letters between Philip Morse, professor of physics at MIT and Harold Smyth, chair of physics at Princeton illustrates the zeitgeist in which all parties operated. On 17 January 1939, Smyth wrote to Morse in response to the latter's letter of recommendation:

> One question always arises, particularly with men interested in theoretical physics. Is Feynman Jewish? We have no definite rules against Jews but have to keep their proportion in our department reasonably small because of the difficulty in placing them.

Morse responded the next day (18 January 1939):

> It had never occurred to me that Feynman might be Jewish until you asked me. On looking up his record, I find that he is. His physiognomy and manner, however, show no trace of this characteristic and I do not believe the matter will be any great handicap to him.[319]

The question was evidently still not resolved until two more letters went from John Slater, chair of physics at M.I.T. to Smyth. In the second, Slater assured Smyth that even though Feynman was Jewish, "as compared for instance with Kanner and Eisenbud, he is more attractive personally by several orders of magnitude." By 09 March, 1939, the case had been made and Smyth advised Slater that Princeton would be offering an assistantship to Feynman for the

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[319] Feynman GRE record (no date), Physics Dept. Records, Box 8, Folder 9, Graduate School, 1934-1942, PRIN-PHY; exchange of letters between P.M. Morse and H.D. Smyth re Feynman 17 Jan 1939, 18 Jan 1939, Physics Dept. Records, Box 6, Folder 3, Departmental Business, 1938-1942, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY.

next academic year. To be fair, after Feynman had completed his degree, Smyth expressed some hope to Wheeler that Princeton might be able to retain Feynman on a permanent basis after the war.[320]

While Princeton did not accept female undergraduates until 1968, Wheeler's remarks concerning Katherine Way, Maria Goeppert-Mayer, and the general under-population of women in the field of physics (noted above), suggest his disagreement with that policy. Indeed, once the admissions policy had changed, Wheeler encouraged talented young women to apply to Princeton, and in at least two cases, lobbied for their admission.[321] In March of 1975, while serving as a visiting professor at the University of Washington, Wheeler wrote to Professor Frank Shoemaker at Princeton to lobby for the admission of Leslie Ann Ambrose and Carol Curry, two high-school students that he had met at an event in Seattle. Thus, we have every indication that throughout his career. John Wheeler, like his mentor Karl Herzfeld, judged students and colleagues based on their willingness to work and their ability to

[320] Letter from H.D. Symth to J.C. Slater 09 Mar 1939, Physics Dept. Records, Box 6, Folder 3, Departmental Business, 1938-1942, Series I, Chairman H.D. Smyth Records, 1933-1953; letter from H.D. Smyth to J.A. Wheeler, re Feynman placement, 18 Jun 1942, Physics Dept. Records, Box 6, Folder 6, Departmental Business, 1938-1942, Series I, Chairman H.D. Smyth Records, 1933-1953, PRIN-PHY. See also Gleick, *Genius,* p 50 for Feynman not being admitted to Columbia as an undergraduate; see p 84 for the quotation in the letter from Slater to Smyth.

[321] Memo from Wheeler to F.C. Shoemaker, 14 Mar 1975, Series I, Princeton Files, Box 1 “A – American Phil”, Folder, “Ambrose, Leslie”, APS-JAW.

contribute to the corpus of knowledge rather than their gender, race, or ethnicity.[322]

In Chapter Two, we learned that Gregory Breit had a keen interest in the welfare of his students and took measures to build a sense of community. Karl Herzfeld, though no less interested in the welfare of his students, tended more toward individual involvement rather than group activities. Wheeler, in the matter of personal involvement with students, seems to have incorporated elements from both Herzfeld and Breit. A good number of the contributions to *Family Gathering* remark on the personal kindness, hospitality, and concern for a student's welfare that John Wheeler demonstrated in his work with his mentees. In fact, to guarantee his accessibility to students, Wheeler regularly scheduled several consecutive advising appointments on Saturdays. In practice, as one appointment overlapped another, these meetings became small-group learning sessions in which the participants had an opportunity to assist others on their various projects. Paul Boynton reports that, in general terms, Wheeler would give priority to whomever had most recently walked through the door, but all would contribute to the discussion, and more importantly, all (i.e. undergraduates, graduate students, and post-docs) had

[322] Mulligan, “Karl Ferdinand Herzfeld,” n.p.

equal standing.[323] Again, this has a familiar ring. Wheeler's Saturday seminars were in the tradition of Karl Herzfeld, who regularly came in on Saturday to meet with students, and Gregory Breit, who often scheduled group activities for his students on Saturday. Herzfeld's predilection for individual attention is evidenced by his choice to schedule Sunday appointments (all but unheard of in academic circles) for at least one student, who happened to be an orthodox Jew.[324]

Of course, Herzfeld was only one of the principal mentors in John Wheeler's career. In the preceding remarks, we have touched upon certain aspects of Breit's mentoring style that were adopted by Wheeler, but this has only just scratched the surface. Let us now examine the influence of Gregory Breit on John Wheeler's mentoring style in some detail.

Section 3.4 Wheeler as Mentor: The Influence of Breit

In the last chapter, we learned that Wheeler's first postdoctoral mentor, Gregory Breit, emphasized the immediately do-able (i.e. calculable) in theoretical physics. Thus, the development of sophisticated computational skills in mathematical analysis among Wheeler's students is more likely

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[323] *Family Gathering,* regarding Wheeler's concern for the well-being of his students, see David Lawrence Hill, 47; Kenneth W. Ford, 84; Arthur Komar, 107; B. Kent Harrison, 182; John R. Klauder, 190; Jacob Bekenstein, 423; J. R. "Hugh" Dempster, 489; For the Saturday meetings see Fred K. Manasse, 258; Cheuk-Yin Wong, 287; Paul Boynton, personal communication with author, 07 Mar 08, used by permission.

[324] Mulligan, "Karl Herzfeld," n.p.

traceable to the influence of Breit rather than to Herzfeld or Bohr. Moreover, the students that John Wheeler worked with as undergraduates are more likely to have acquired (or polished) particular skills—especially mathematical skills—than those students who only did graduate work with Wheeler.

At this point, it may be useful to remind ourselves of the distinction between mathematical and theoretical physics from Chapter One: Theoretical Physics employs mathematical analysis to address the general nature of a class of phenomena (e.g. acceleration) whereas Mathematical Physics is typically focused on either mathematical descriptions of a given phenomenon (e.g. the electric field of an electron) and/or the development of mathematical techniques that can be applied to describe certain physical phenomena (e.g. Fourier analysis). In short, Theoretical Physics is distinguished from Mathematical Physics its generalized frame of reference.

Here too, it is useful to reflect on Wheeler's view that self-confidence is a pre-requisite to the practice of science. Even though Wheeler came to Hopkins and later, to Breit at NYU, with “no shortage” of confidence in his abilities, the experience of producing five papers out of his work with Breit could only have enhanced his [Wheeler's] conviction that, in time, he could

solve any problem.[325] Therefore, the best evidence of the transmission of Breit's influence to Wheeler's undergraduates would include both the acquisition of mathematical skills and the inculcation of confidence in their ability to solve difficult problems.

One such case in point is Robert Marzke, who went from Princeton (A.B. 1959) to earn a Ph.D. at Columbia (1966). At Princeton, under John Wheeler's guidance, Marzke wrote a senior thesis titled, "The Theory of Measurement in General Relativity." In *Family Gathering,* Marzke speaks of the confidence that Wheeler inculcated in his students as an exemplar for physics education:

> While perhaps not as important as your work with graduate students, your willingness to direct many undergraduates in their first attempts at research sets an example for everyone in the area of higher education, I feel. Those of us who worked with you recall the wealth of ideas and projects, as well as your confidence in our ability to tackle them despite our inexperience. This made us especially determined to produce results, and on occasion we even did so. The value of this kind of learning to a student is inestimable. It is university education at its best.[326]

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[325] Wheeler and Ford, *Geons,* 84, on self-confidence as necessary to the practice of science; Ibid, 277, Wheeler notes that even as a boy he had "not been short on confidence."; Ibid, 114-115, 119. The papers (also cited in chapter 2) include: J. A. Wheeler and G. Breit, "Li+ Fine Structure and Wave Functions near the Nucleus," *Physical Review* 44 (1933), 948; J. A. Wheeler, "Interaction Between Alpha Particles," *Physical Review* 45 (1934), 746; G. Breit and J. A. Wheeler, "Collision of Two Light Quanta" *Physical Review* 46 (1934): 1087-1091; F. L. Yost, J. A. Wheeler, and G. Breit, "Coulomb Wave-Functions," *Terrestrial Magnetism* 40 (1935), 443-447; F. L. Yost, J. A. Wheeler, and G. Breit, "Coulomb Wave Functions in Repulsive Fields," *Physical Review* 49 (1936), 174-89.

[326] *Family Gathering,* Robert Marzke, 141.

In Marzke's letter, we have the aforementioned ‘best evidence’ that Wheeler instilled both confidence (or at least the unwillingness to back down from complicated problems) and mathematical expertise in his undergraduate charges.

Another example is Joel Primack who earned his A.B. in physics at Princeton in 1966 and his Ph.D. at Stanford in 1970. Primack’s Senior Thesis, “Unified Model Calculations in Fission Theory”, was completed under the guidance of Gerald E. Brown. While this work plainly involved a good bit of complicated analysis, Primack was very appreciative that Wheeler framed the problem in a broader context. In *Family Gathering*, he wrote:

> Both by instruction and example, you have helped to shape my career in physics ... You inspired your students to take the entire natural world for our arena as physicists, discouraging narrow specialization, and you taught us to approach all physical problems in a challenging and productive way ... there is one other thing that I learned as your student, and that is the realization that physics at its best is a warmly human enterprise. For this great lesson, and for your friendship, I am deeply grateful.[327]

There are two elements in this letter that need to be unpacked. One is the key phrase, “challenging and productive.” Stated alternatively, Wheeler was exhorting his charges to take on difficult problems (i.e. approach problems with confidence), find an avenue of attack, and solve what can be solved—all strategies that Wheeler would have had to exercise when he worked under the supervision of Gregory Breit.

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[327] *Family Gathering,* Joel R. Primack, 506.

A second major point to amplify is the enduring nature of Wheeler's influence. Primack's letter was written in 1977, at least eleven years after he had worked with John Wheeler. Moreover, although Joel Primack was not one of John Wheeler's advisees, he nonetheless credits Wheeler with helping "to shape his [Primack's] career in physics." Joel Primack is hardly a unique case. As will be seen elsewhere in this study, my research has uncovered a number of students who were profoundly influenced by Wheeler even though they had relatively little contact in a prescribed academic sense (i.e. no formal advising relationship).

A third example of mentoring in the "Breit" mode should cement the case. For his Senior Thesis, Jim Ritter chose a topic ("The Cauchy Problem for the Klein-Gordon and DeWitt Equations") that involved very sophisticated and intricate mathematical reasoning, and for his advisor, he chose John Wheeler. [328] It seems quite likely that Wheeler would have had to teach Ritter some of the nuances in the formulation of this problem, but, as we read Ritter's 1977 letter from *Family Gathering,* it is just as obvious that more than mere instruction was involved here:

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[328] Princeton University, "James G. Ritter," Princeton University Senior Thesis, http://libweb5.princeton.edu/theses/thesesid.asp?ID=79578 (22 Aug 2005). The Cauchy Problem is a partial differential equation that describes unique solutions to mathematical functions that are centered at the origin of a coordinate system and describe a boundary with unique and particular features. The Klein-Gordon Equation is a relativistic version of the Schrödinger equation that describes quantum motion. The DeWitt (or Wheeler-DeWitt) equation describes a wave function of the universe in the context of quantum gravity.

> It is no easy thing, I think, for a former student to write of what he owes to a teacher; particularly when that teacher was for him a truly formative influence. Indeed, to say 'a former teacher' is not really accurate, for a truly great teacher leaves within each of his students, a slice of himself, a small kernel which forms such an integral part of the student that it grows, develops, and changes along with its host throughout all the years that follow.

As we read further, we see that Wheeler's influence went far beyond physics.

> So I (along with so many) owe to you not only what I have learned of the beauty and delight of science (though I have never had a more gifted and inspiring teacher) but also a manner of seeing the world, of creating order out of that apparent chaos which surrounds us all. And this is a knowledge which illuminates not only that work I have done or shall do in physics, but in every area of my life; in politics, in art, even in personal relations. Not that we have always agreed in these areas – nor do I think you would have wanted that – but that your insistence on honest and unflinching analysis, your deep-rooted belief that there is a fundamental beauty and simplicity to truth, and your understanding and wise compassion have always been for me the sought-for framework and goal of any undertaking.[329]

It is also noteworthy that, here again, Wheeler's influence was enduring. Ritter's 1977 letter was composed some twelve years after he completed his thesis under Wheeler's supervision.

As impressive as these testimonials are, one should continue to bear in mind that these are letters from students whose experience with Wheeler was on the undergraduate level. Before they were in a position to serve as a mentor, these people would have had to serve a graduate level apprenticeship under someone other than John Wheeler. Under those circumstances, one wonders how much of the reasoning style that was passed to succeeding

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[329] *Family Gathering,* Jim Ritter, 531-532.

generations of physicists was directly traceable to Wheeler and how much was an amalgamation of various mentors' styles.

The previously examined letter of Edward F. Redish (AB Princeton, 1963; Ph.D. MIT 1968) is informative on this score. Redish reports:

> It isn't always possible to tell with whom a person studied, but there are particular aspects of the Wheeler style that many of us who had the good fortune to work with you have tried to emulate. First of all you have always had a wide-ranging enthusiasm for all of science and for physics in particular ... Your excitement about understanding everything from brain waves to gravity waves struck a resonant chord in us, heightening our own love of science.

After discussing Wheeler's ability to 'extract the physics from the mathematics,' Redish continues:

> I try to emphasize this outlook in my own teaching at all levels, from graduate students to non-calculus premeds. Every one of my courses begins with the Wheelerian: "Redish's First Moral Principle: Always make a mental picture," followed by the direct Wheelerian commandments: "Guess the answer." and "Build up your tool kit."
>
> You also taught me that nothing is too hard to be taught to anyone. Your ability to distill difficult concepts into a clear and simple presentation has strongly influenced my teaching style ... I feel that my attitude toward physics and my entire career was influenced in an important way by your teaching even though our interaction was limited to a single year.[330]

Based on this report from Edward Redish, it is evident that even undergraduates who enjoyed a very limited window of direct interaction with John Wheeler, were nonetheless strongly influenced by him to the point where they transmitted his style of doing physics on to their own students.

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[330] *Family Gathering,* Edward F. Redish, 270-271.

The renowned cosmologist James Hartle (AB, Princeton, 1960), for example, seems to have had only one class in which John Wheeler was the professor of record. Hartle's senior thesis ("The Gravitational Geon") was written under the supervision of Dieter Brill (a former Wheeler student), and he went on to Caltech to earn a Ph.D. under the supervision of (future Nobelist) Murray Gell-Mann (1929 –).[331] Nonetheless, despite Hartle having comparatively little direct and-or formal pedagogical interaction with John Wheeler, Wheeler's influence on his [Hartle's] career appears to have been substantial. He concluded his letter:

> You suggested looking into variational principles for rotating relativistic stars and together with David Sharp [a Wheeler undergraduate advisee], I did. This led to my early work on relativistic stellar structure much of which was pursued with your student Kip Thorne. Eventually, at Santa Barbara [UC Santa Barbara] I came to see so many interesting but solvable problems in relativity that I made it my dominant area of research and it has remained so since.
>
> Even now in reading this over I am impressed with the crucial role you have played at the significant stages of my career. It is therefore with appreciation for your teaching, thanks for your

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[331] *Family Gathering,* James B. Hartle, 206-207; Appendix E, Senior Theses at Princeton, 1938-1978, 1988-1994; See also James B Hartle, "James B. Hartle's Homepage", http://www.physics.ucsb.edu/~hartle/ (02 Dec 2008), and Google Scholar, search "JBHartle", http://scholar.google.com/scholar?as_q=&num=10&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JB+Hartle%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= (02 Dec 2008). Among other notable works, Hartle achieved considerable distinction for his 1983 paper "Wave Function of the Universe" (co-authored with Stephen Hawking). As per Google Scholar (02 Dec 2008), this paper has been cited nearly 1800 times.

> counsel, and admiration for your example that I send you and Janette my best wishes.[332]

Beyond the superlatives and testimony of pedagogical embodiment, we also see more subtle concepts emerge in this collection of remembrances.

In each of the above letters, one gets a sense of Wheeler's contagious enthusiasm for physics. Ken Ford, co-author of Wheeler's autobiography, reports that Wheelers enthusiasm—even about classical mechanics—convinced him [Ford] that John Wheeler was the best choice to guide his dissertation.[333] Joel Primack wrote that doing physics with Wheeler was “a warmly human enterprise,” and Robert Marzke spoke of Wheeler's “confidence in our ability to tackle [complex problems].” Edward Redish very clearly demonstrated a sense of intellectual lineage when he explicitly stated that Wheeler's enthusiasm is a quality that he [Redish] consciously attempted to emulate with his own students.

Edward Redish's letter also speaks indirectly to the issue of Breit's influence on John Wheeler as a mentor. The reference to a “Wheelerian commandment” to 'build up your toolkit' is significant. As we have seen, John Wheeler spent much of his postdoctoral year with Breit doing very involved calculations. As noted in Chapter 2 (and above), five of Wheeler's published papers stemmed from his year with Breit. Along the way, Wheeler was able to expand his mathematical toolkit (e.g. when Breit taught him to use Coulomb

[332] *Family Gathering,* James B. Hartle, 207.
[333] Ken Ford, in a telephone conversation with the author (03 May 2006).

Wave functions in analysis) such that he became an extremely proficient mathematical craftsman. Indeed, Professor Richard Matzner, a colleague of Wheeler at Texas as well as an intellectual descendent of John Wheeler (through Charles Misner at Maryland) observed that:

> I always had a sense of John as a global thinker, in the manner of Bohr, as contrasted with the focused and mathematically rigorous reasoning style of Steven Weinberg. However, in my examination of John's early work, I have come to see him as a formidable calculator.[334]

The idea of a mathematical toolkit, especially as it relates to the craft of doing theoretical physics, is an important concept to grasp. Richard Feynman attributes much of his success to having taught himself a good deal of mathematics. Because he was self-taught, Feynman had a "different box of [mathematical] tools."[335] Of course, having the tools is only a part of becoming a physicist. One also must learn how and where to apply the tools.

Consider the art of carpentry. There is a profound difference between an amateur handyman and a master craftsman. For example, even though a handyman and a master carpenter may each complete a cabinet, there is likely to be a substantial difference in quality. Put simply, the difference between an amateur and a craftsman is that the former knows how a tool works; the latter knows how to work a tool. The analogy holds with physicists

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[334] Wheeler and Ford, *Geons,* 114-115, 119; The papers stemming from Wheeler's year with Breit are listed in a footnote in Chapter 2 and are numbers 4, 5, 7, 9, and 10 in Wheeler's bibliography. Also, Richard Matzner, personal communication with the author, 05 Jun 2008.

[335] Feynman and Leighton, *Surely You're Joking Mr. Feynman*, 77-78.

and mathematics. Virtually all physicists possess the mathematical literacy to know how a given function works. The best theoreticians however, not only know the functions, they know how and where to most profitably apply them. A clear example of this is found in John Wheeler's research notebook "Nucleonics I." The context of Wheeler's line of reasoning is the mechanism of nuclear fusion in the hydrogen bomb:

> "Before developing further, have to decide what kind of coordinates to use; and before deciding this, have to see how electrostatic energy looks.
>
> Wrong. We want to use trilinear diagram, even for large displacements. Hence we must use A, B, C $eA = a/R_o$, etc; $1 + \xi = e^{2(A+B)} = 1 + 2(A+B) + ½\ 4(A+B)^2 + 1/6\ (A+B)^3$
>
> $\xi = 2(A+B) + 2(A+B)^2 + 4/3(A+B)^3 + \ldots$
>
> [further on the page, Wheeler continues] Can already smell out important result.[336]

For those readers who do not routinely perform third order differential equations, some explication may prove useful.

Imagine a plumber who is attempting to replace a broken pipe. As she surveys the problem, she realizes that there is no room in the problem area for her to move her wrenches. Thus, in order to effect repairs, she has to prepare a sub-assembly of pipes, and most importantly, she must prepare that assembly in such a manner that the act of screwing in the sub-assembly does not unscrew the individual components that comprise it. In essence, Wheeler saw how the problem was shaping up, and he took steps to simplify the

[336] John A. Wheeler, Nucleonics I, 17 Jul 1951, p 54-55, APS-JAW.

calculation without sacrificing any potential insight. In light of the foregoing, what can we particularly identify as contributions to the enterprise of physics that came though John Wheeler from Gregory Breit?

Obviously the corpus of physical knowledge benefited from the five papers that grew out of Wheeler's year of collaboration with Breit. By contrast with the cumulative effect of Wheeler's papers however, the craftsmanship Wheeler acquired was multiplicative in that it was passed on to succeeding generations of physicists.

Then too, there is the Wheelerian commandment: "Guess the answer." This dictum (or something like it) occurs often in the reminiscences of Wheeler's former students.[337] The point that Wheeler was communicating was 'one must apply one's intelligence and look beyond the imminent details of a problem.' Hard work (i.e. laborious calculation) in and of itself, is insufficient to the task of theoretical physics. The reader may recall here the characterization of a robust work ethic from Chapter 1: "It is good to work hard. It is better to work smart. If you can work hard and smart, you'll always find success."[338]

In the context of theoretical physics, it is advisable to begin by developing a sense of magnitude: how big or little is the phenomenon one is

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[337] For example, *Family Gathering,* J. R. "Hugh" Dempster, 489; Jacob Bekenstein, email to the author (16 Sep 2005); Peter Vajk, email to the author (21 Sep 2005); Edwin F. Taylor, "The Anatomy of Collaboration," in *Magic Without Magic: John Archibald Wheeler; A Collection of Essays in Honor of His Sixtieth Birthday,* ed. John R. Klauder (San Francisco: W. H. Freeman, 1972): 474-485, 484-485.

[338] Again, this insight is the gift of my grandfather, Thorwald Christensen.

attempting to calculate. Also, before undertaking a detailed computation, it is often useful to perform a dimensional analysis (i.e. determine the dimensions or units of the final answer that is sought). If the final answer will be a unit of force in the cgs (centimeter-gram-second) system of measurement, how will the units associated with the variables in the problem need to be algebraically manipulated so that the final answer is in dynes? Hence, one is well advised to "guess the answer" before beginning to calculate.

On the face of it, these suggestions are straightforward. In fact, nearly all first year physics and chemistry students are taught dimensional analysis. As the calculations become more complex however (e.g. a three-body problem), keeping the dimensions and their magnitudes in algebraic order becomes more challenging. On the scale of elementary particles, simply keeping track of the magnitude of forces can be problematic. The difficulty is that electromagnetic forces are inversely proportional to the square of the distance between the two (or three) charged particles. Thus, as the distance between particles approaches the sub-atomic scale (the radius of a proton is on the order of 10^{-15} meters) the forces exerted between the particles increase exponentially.[339]

These and other complications (e.g. even though the spectrum of mathematical solutions is continuous, the energy of any individual particle is

[339] Francis W. Sears, Mark W. Zemansky, and Hugh D. Young, *University Physics* 6th Ed. (Reading, MA: Addison Wesley, 1992), 596-603.

quantized), require one to perform 'reality' checks (i.e. “guess the answer”) before computing each step of the calculation. While there is no instance in which Wheeler directly ascribes this bit of wisdom to Gregory Breit, it seems reasonable to presume the tacit communication of this lesson over the several months that John Wheeler sat calculating in the same office with Breit.

Assertive vision is yet another element of mentoring skill that emerges from Edward Redish's letter to John Wheeler. Here, I am not referring to vision in the sense of being visionary, though by all accounts Wheeler also had that quality. Rather, I am referring to the ability to visualize the end product (the same vision that enables a master carpenter to see a finished cabinet in a stack of wood) and further, to enable others (i.e. Wheeler's students) to visualize the end product of their labors. This goes well beyond developing a sense of magnitude and the unit dimensions of the answer. In Redish's words, John Wheeler helped him see beyond the mathematics to, “the working model; a real thing with nuts, bolts and rust.”[340] In other words, at least in part because of his formidable mathematical skill, John Wheeler was able to see through the mathematics to the end product, the physical reality that his students were attempting to model. This sort of revelation was not confined to undergraduates.

Richard Feynman recalls his early work in quantum electrodynamics. He had begun wrestling with the problem of an electron’s force on itself during

[340] *Family Gathering,* Edward F. Redish, 270-271.

his undergraduate years at MIT, eventually setting the calculation aside. Later, in graduate school at Princeton, Feynman returned to the problem. In the fall of 1940, Feynman believed that he had made a breakthrough. He showed his calculations to John Wheeler, (then) Feynman's thesis advisor. Feynman reports:

> Wheeler said right away: Well, that isn't right because it varies inversely as the square of the distance of the other electrons, whereas it should not depend on any of these variables at all. It'll also depend inversely upon the mass of the other electron; it'll be proportional to the charge on the other electron.

Feynman continued:

> What bothered me was, I thought he must have done the calculation. I only realized later that a man like Wheeler could immediately see all that stuff when you give him the problem. I had to calculate, but he could see.
>
> Then he [Wheeler] said: And it'll be delayed—the wave returns late so all you've described is reflected light.[341]

This sort of assertive vision with regard to mathematics is the product of having done countless calculations. Wheeler could 'see' what Feynman had to calculate because he [Wheeler] had performed far more calculations that

[341] Feynman and Leighton, *Surely You're Joking,* 77-78; Feynman also shared this anecdote in his Nobel Lecture. See, Richard P. Feynman, "The Development of the Space-Time View of Quantum Electrodynamics," Nobel Lecture (11 Dec 1965), http://nobelprize.org/physics/laureates/1965/feynman-lecture.html (24 Mar 06); Also in *Nobel Lectures, Physics 1963-1970* (Amsterdam: Elsevier Publishing Company, 1972.), n.p.

involved light quanta; and these are precisely the kind of calculations that Wheeler had performed under the supervision of Gregory Breit.[342]

Perhaps more importantly, because of these enhanced abilities with sophisticated analytical tools, John Wheeler was able to effectively communicate with junior physicists (such as Redish and Feynman) who tended to think in equations rather than physical phenomena. Wheeler could look at a board filled with dense, closely reasoned equations and reveal Redish's 'working model' and Feynman's reflected light. David L. Hill, a Wheeler Ph.D. student who co-authored an important paper on the structure of the nucleus with him, described Wheeler's assertive vision very succinctly: "You show a virtuoso facility for applying analytical and mathematical stratagems to elicit glimpses of the terrain and possibly of the solution before a massive attack is made on the problem." [343]

Finally, there is the matter of Breit's concern for his students. Although his prickly personality may have obscured this quality to some, Breit cared

[342] Wheeler and Ford, *Geons* 114-115, 119; Wheeler interview with Ford, 603 (03 Jan 1994).
[343] *Family Gathering,* David L. Hill, 47; The paper ("Nuclear Constitution and the Interpretation of Fission Phenomena," *Physical Review,* 89, no. 5 (01 March1953):1102-1145) has been cited more than 984 times. Google Scholar, "DL Hill", http://scholar.google.com/scholar?as_q=&num=20&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22DL+Hill%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=some&as_subj=phy&hl=en&lr=&safe=off (04 Dec 2008); See also Wheeler interview with Ken Ford (14 Feb 1994 – 21 Mar 1994), 1207, 1901, 1902, 1906 and esp. 1703, 2320; Wheeler interview with Finn Aaserud (04 May 1988), n.p.

very deeply about his students' welfare. This concern took several forms. The Maryland physicist McAllister Hull, author of Breit's biographical memoir, reports that the health of his students was always a concern. Breit evidently admonished Gary Herling (then his student) that, “an hour of exercise a few times during the week is much better than several hours of exercise every few weeks.” Wheeler has recalled that he and other of Breit's students were often “invited” to accompany Breit on vigorous walks through the suburbs of New York.[344] In matters of publication, Breit was very careful to see that his students got proper credit for their contribution to a paper. McAllister Hull, noted that John Wheeler spoke of Breit's “‘kindness’ in crediting his work with joint authorship on papers.” This conscientiousness with regard to sharing credit is echoed by Wheeler's students.[345]

Another aspect of Breit's concern for his students was his unrelenting efforts to find employment and career opportunities. Wheeler believes that a letters from Breit to the National Research Council and to Niels Bohr helped secure the renewal of Wheeler's postdoctoral fellowship and get him to

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[344] McAllister Hull, “Gregory Breit: July 14, 1899 – September 11. 1981,” *Biographical Memoirs*; Wheeler interview with Ken Ford (03 Dec 1994), 504. Here Wheeler also remarks that Breit, “had something of the German professor’s sense of responsibility to his research students”; See also Wheeler and Ford, *Geons,* 108, for the notion that Breit's 'invitations' were less than completely voluntary.

[345] Hull, “Gregory Breit,” *Biographical Memoirs*, n.p. [Since the electronic copy of this memoir is not paginated it is impossible to direct the reader to specific locations for these quotations.]; In the case of Wheeler's students, see *Family Gathering,* Dieter Brill, 164; Fred K. Manasse, 258; Kip S. Thorne, 306.

Copenhagen for his second postdoctoral year. Hull observed that Breit was extremely well connected in the physics community. In 1968, more than 200 colleagues and former students attended a symposium in Breit's honor at Yale. Breit was well known to use these connections to the benefit of students and colleagues. In fact, Hull refers to Breit's efforts on his student's behalf as "legendary." As part of this process, Breit would frequently invite his students to parties at his house where they would meet and socialize with luminaries of physics (e.g. Werner Heisenberg). Breit's colleagues also benefited from his stature in the profession. As we have seen, in 1936, when (future Nobelist) Eugene Wigner lost his position at Princeton, Breit was instrumental in helping Wigner find a suitable position at Wisconsin.[346] Here too, we find a resonance in Wheeler's students; many of whom specifically credit Wheeler with advancing their career.[347] During the early 1950's Wheeler lobbied Harold Smyth, chair of Princeton's physics department, to release some of his [Wheeler's] graduate students to work on the hydrogen bomb:

> Insofar as graduate students are going to have to get part of their training working on university sponsored war projects"—an assertion seemingly so obvious that Wheeler felt no need to

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[346] Wheeler interview with Ken Ford (10 Jan 1994), 701; Hull, "Gregory Breit," *Biographical Memoirs*, n.p.

[347] See *Family Gathering,* David L. Hill, 47; Charles Misner, 125-126; Daniel Sperber, 144; John G. Fletcher, 200; Masami Wakano, 231; Cheuk-Yin Wong, 287; Kip S. Thorne, 309; Robert Geroch, 351.

> justify it—"it will be hard for them to do better than on the thermonuclear project for all-around range of ideas.[348]

In sum, the evidence indicates that, at a minimum, Breit reinforced the people skills that Wheeler had learned and/or developed under Herzfeld. Most significantly however, Breit helped Wheeler become a craftsman in the use of mathematics. In the next section, we move from Wheeler's skill at calculation to his skill at conceptualization.

Section 3.5 Wheeler as Mentor: The Influence of Bohr

As has been noted above, many of John Wheeler's former students and outside observers see a clear linkage between the mentoring styles of Wheeler and Niels Bohr. So what, in the eyes of Wheeler's students, makes Wheeler seem like Bohr? Was it Wheeler's penchant for explication in terms of physical constructs (e.g. what Edward Redish referred to as a 'working model complete with nuts, bolts, and rust'), his philosophy of science, or (beyond a carefully reasoned philosophy) some deeply-rooted faith in the rationality of the physical universe?

Jacob Bekenstein, who achieved considerable distinction for his work linking the surface area of a black hole with entropy, sees John Wheeler as more prophet than philosopher. In a letter of 16 September 2005, Bekenstein observed:

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[348] David Kaiser, "Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II," *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002): 131-160, 144.

> Wheeler is often prophetic. Two little known examples: In a review in 1966 he suggested that the Crab Nebula gets its energy from the spin of a neutron star, mentioning that this requires good coupling between star's magnetic field and surrounding plasma clouds. A year later the pulsars were discovered and soon interpreted by Gold as magnetized rotating neutron stars. When the Crab pulsar was discovered, it became clear that it indeed powers the emissions and some of the expansion of the Crab nebula. Another example: back in the 40's Wheeler studied the theoretical properties of what he called a “polyelectron", an analog of the ionized hydrogen molecule with the protons replaced by positrons. It is interesting as a pure QED three-body problem. Polyelectrons were first prepared at Bell Labs in 1981.[349]

Whether one sees John Wheeler as a physicist, a philosopher or a prophet, it is clear that Wheeler (like Bohr) tended to look for physical phenomena—for anschaulich properties—to support the mathematical formalisms of theoretical physics. Why this is so becomes apparent when we look to Richard Feynman's 1965 Nobel lecture.

The most famous of Wheeler's physical conjectures occurred while he and his (then) student Richard Feynman were attempting to eliminate some persistent and troublesome infinities in the mathematics that describe quantum

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[349] Jacob Bekenstein, email to author, 16 Sep 2005; Wheeler's conjecture on the rotating neutron star in the Crab Nebula is also recounted in *Family Gathering,* 423; See also, Google Scholar, “JD Bekenstein”, http://scholar.google.com/scholar?as_q=&num=30&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JD+Bekenstein%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=some&as_subj=phy&hl=en&lr=&safe=off (04 Dec 2008).Bekenstein's 1973 paper, “Black Holes and Entropy” (*Physical Review D* 7, no. 8 (15 Apr 1973):2333-2346) has been cited more than 1700 times; His 1974 paper, “Generalized Second Law of Thermodynamics in Black Hole Physics” (*Physical Review D* 9, no. 12 (15 Jun 1974):3292-3300) has been cited more than 450 times.

electrodynamics (QED).[350] One evening, Wheeler telephoned Feynman with a novel conceptualization:

> **[Wheeler]:** Feynman, I know why all electrons have the same charge and the same mass.
>
> **[Feynman]:** Why?
>
> **[Wheeler]:** Because, they are all the same electron! ... Suppose that the world lines which we were ordinarily considering before in time and space—instead of only going up in time were a tremendous knot, and then, when we cut through the knot, by the plane corresponding to a fixed time, we would see many, many world lines and that would represent many electrons, except for one thing. If in one section this is an ordinary electron world line, in the section in which it reversed itself and is coming back from the future we have the wrong sign to the proper time - to the proper four velocities—and that's equivalent to changing the sign of the charge, and, therefore, that part of a path would act like a positron.
>
> **[Feynman]:** But, Professor, there aren't as many positrons as electrons.
>
> [**Wheeler]:** Well, maybe they are hidden in the protons or something.

Feynman concludes:

> I did not take the idea that all the electrons were the same one from him as seriously as I took the observation that positrons

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[350] The problem was that the mathematical terms describing finite physical phenomena went to infinity in the equations. Quantum Electrodynamics (QED) is the study of the interaction of charged particles at the quantum level (i.e. electrons, photons, etc.).

> could simply be represented as electrons going from the future to the past in a back section of their world lines. That, I stole! [351]

Later in his speech, Feynman credits John Wheeler's conjecture about the physical nature of positrons as an important clue in the QED work for which Feynman was awarded the Nobel Prize.[352]

Feynman also alerts us indirectly to the importance of physical conceptualization of phenomena (anschaulich) in mentoring. Here it will be useful to revisit the QED controversy of the late 1940s. The reader may recall that Feynman shared his 1965 Nobel prize with Sin-Itiro Tomonaga (1906 – 1979) and Julian Schwinger (1918 – 1994). Each of the three men took a different approach to QED, and the formalisms developed by Feynman and Schwinger seemed particularly far removed from one another. These widely disparate formalisms were eventually shown to be equivalent by the

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[351] Richard P. Feynman, "The Development of the Space-Time View of Quantum Electrodynamics," Nobel Lecture (11 Dec 1965), http://nobelprize.org/physics/laureates/1965/feynman-lecture.html (24 Mar 06); Also in *Nobel Lectures, Physics 1963-1970* (Amsterdam: Elsevier Publishing Company, 1972.), n.p.

[352] Feynman, " The Development of the Space-Time View of Quantum Electrodynamics," n.p.; Oddly enough, there is no mention of this story or Wheeler's contribution to Feynman's work in either of Feynman's autobiographical collections of anecdotes (i.e. Richard Feynman and Ralph Leighton, *Surely You're Joking Mr. Feynman: Adventures of a Curious Character* (New York: W. W. Norton & Co, 1985) and Richard P. Feynman with Ralph Leighton, *What Do You Care What Other People Think* (New York: Bantam Books, 1988)); Moreover, neither the story nor Wheeler's name appear in Richard P. Feynman, *QED: The Strange Theory of Light and Matter* (Princeton, NJ: Princeton University Press, 1985); The 'all the same electron' story is however, retold by Feynman's biographer James Gleick (Gleick, *Genius,* 122-123) and Feynman's former colleague and Nobelist Murray Gell-Mann (Gell-Mann, Murray. "Dick Feynman—The Guy in the Office Down the Hall." *Physics Today* 42, no.2 (Feb 1989): 50-54, 52).

mathematician Freeman Dyson.[353] This circumstance is, of course, similar to the situation in quantum mechanics in the late 1920s when the Nobelists Werner Heisenberg and Erwin Schrödinger adopted two very different approaches to the problem of quantum states. And yet, Heisenberg's matrix algebra and Schrödinger's wave equations described exactly the same phenomena.[354] On its face, this situation would not seem to be problematic. Just as there are no preferred frames of reference, there are bound to be multiple perspectives from which to view or analyze a physical process.

The drawback, as Feynman noted in his Nobel lecture, is that even though varying approaches to a problem may be equivalent mathematically, they are not typically equivalent conceptually:

> Physical reasoning does help some people to generate suggestions as to how the unknown may be related to the known. Theories of the known, which are described by different physical ideas may be equivalent in all their predictions and are hence scientifically indistinguishable. However, they are not psychologically identical when trying to move from that base into the unknown. For different views suggest different kinds of modifications which might be made and hence are not equivalent in the hypotheses one generates from them in one's attempt to understand what is not yet understood. I, therefore, think that a good theoretical physicist today might find it useful to have a wide range of physical viewpoints and mathematical expressions of the same theory (for example, of quantum electrodynamics) available to him.

Feynman went on to say, “This may be asking too much of one man.”[355]

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[353] Gleick, *Genius,* 267-270.
[354] David C. Cassidy, *Uncertainty: The Life and Science of Werner Heisenberg* (New York: Freeman, 1993), 212-213.
[355] Feynman, Nobel Lecture (11 Dec 1965), n.p.

Whether or not it is asking too much of one man, Feynman's statement describes the anschaulich methodology of John Wheeler. In *Geons,* Wheeler observes, “There are many modes of thinking about the world around us and our place in it. I like to consider all the angles from which we might gain perspective on our amazing universe and the nature of existence.”[356] Cheuk-Lin Wong, a Wheeler Ph.D. protégé observes, “He [Wheeler] has an inventive mind that bodes no boundaries. His 'blackhole,' 'wormhole,' 'geons,' [and] 'quantum foams' have now become familiar terms in physics vocabulary.”[357] A key point to be re-emphasized here (in paraphrase of Feynman) is that, although the language of mathematics lends itself to precise description, as often as not, physical processes can be mathematically ambiguous, Feynman, Schwinger, and Tomonaga all provided separate and precise mathematical descriptions of QED. Given this circumstance, Niels Bohr (despite his objection to Feynman's use of diagrams at Pocono) was reluctant to place too much reliance on mathematical formulations.[358] Similarly, John Wheeler chose to emphasize physical models and let the physics drive the development of

[356] Wheeler and Ford, *Geons,* 153; This thought is also expressed in the Wheeler interview with Weiner and Lubkin (05 Apr 1967), 12; and also the Wheeler interview with Finn Aaserud (04 May 1988), n.p.; *Family Gathering,* B. Kent Harrison, 182; Also in Jacob Bekenstein, email to author (16 Sep 05).
[357] Cheuk-Yin Wong, email to the author (25 Oct 2005).
[358] Pais, *Niels Bohr's Times*, 20, 178-179.

equations rather than allowing the mathematics to be the conceptual engine.[359]

Section 3.6 Wheeler as Mentor: A Style of His Own

This chapter has aimed to correlate the sentiments of John Wheeler's students with what we know of Wheeler's relationship with his mentors. Several questions prompted these comparisons. First among these was: If Wheeler saw Bohr more as a collaborator than a mentor, how did he see himself in relation to his own students? A number of Wheeler apprentices have written about the priority he placed on helping his students as well as the respect that they were accorded. Ken Ford observed that "we learned [physics] by watching John Wheeler learn."[360] Kip Thorne has written that, from their very first meeting, Wheeler made him [Thorne] feel like a colleague rather than a student. Moreover, Thorne continues, "Wheeler's paramount goal was the education of his fledglings, even if that slowed the pace of discovery."[361] Wheeler's assistance, however, was not limited to professional

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[359] See *Family Gathering,* Kip Thorne, 306-307; Frank Zerilli, 533; B. Kent Harrison, 182; Jacob Bekenstein, 423-424; Fred K. Manasse, 258-259, among others.

[360] *Family Gathering,* Kenneth W. Ford, 84.

[361] Thorne, *Black Holes and Time Warps;* the reference to collegiality is from 262; the quotation is taken from 270. Kip S. Thorne, "Nonspherical Gravitational Collapse: A Short Review," in *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday,* ed. John R. Klauder (San Francisco: W. H. Freeman, 1972), 231. Here, Thorne emphasizes Wheeler's collegial approach to a brand new graduate student.

matters such as research problems, thesis work, and publication. Many of the *Family Gathering* letters speak to Wheeler's “warmth,” “courtesy,” and “concern for his students.”[362] For his part Wheeler has observed that, “I can learn only by teaching.” From that conviction, he has developed the axiom: “Universities have students to teach the professors.”[363] Plainly, Wheeler sees his students more as collaborators than as apprentices.

This chapter also sought to address the question of pedagogical heritage. Specifically, what aspects of Wheeler's style of doing physics did (or do) Wheeler's former students transmit to their intellectual progeny? Again, a number of contributors to *Family Gathering* (including Dieter Brill, Daniel Sperber, Jacob Bekenstein, John Toll, and Larry Shepley) allude to adopting elements of Wheeler's style in the classroom or when advising their students. Others, most notably Kip Thorne, Ken Ford, and Fred Manasse remark that they have consciously worked to emulate John Wheeler's style over the spectrum of activities in their professional careers. Thorne, in particular, wrote extensively about attempting to incorporate John Wheeler's code of ethics for scientific research, as well as Wheeler's style of research, writing and lecturing

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[362] See *Family Gathering,* Dieter Brill, 164-165; B. Kent Harrison, 182; Cheuk Yin Wong, 287; Kip S. Thorne, 306-309; Brendan Godfrey, 391; Jacob Bekenstein, 423-424; J. R. Hugh Dempster, 489-450.
[363] Wheeler interview with Ken Ford (14 Feb 1994-10 Jan 1995). The sentiment 'Universities have students to teach professors,” is expressed on 1209, 1906, and 2318. The conviction that he has to teach in order to learn is expressed on 1704. See also Wheeler interview with Charles Weiner and Gloria Lubkin (05 April 1967). The sentiment of learning by teaching is also expressed on 8; See also Wheeler and Ford, *Geons,* 150.

into his own pedagogy.[364] Thorne also recalls one particularly memorable day at Caltech when some of his students approached him with a passage from the Misner-Thorne-Wheeler opus *Gravitation.*[365] Their complaint was that the passage in question was too “Wheeleristic” and that Thorne should have used his influence with Wheeler to “tone it down.” Thorne gleefully replied, “Wheeler did not write that section: *I* wrote it!” [Thorne's emphasis].[366]

Finally, have the assessments of Wheeler's students changed between 1977 and 2008? If so, how? If anything, Wheeler's students' fondness for him has grown over the years. As any student of oral history knows, admiration tends to appreciate over time. Even so, the hope was to uncover some articulation of how Wheeler's mentoring methodology had evolved over time. This was only partially successful.[367] On 27 October 1976, Cheuk-Yin Wong wrote a letter to be included in *Family Gathering.* It began as follows:

> In looking back on my happy years of apprenticeship under your guidance, I was reminded of the traditional Confucian definition of a great teacher as someone who is able to pass on to others what was transmitted from the past, and in the process, opens up great avenues for future generations.[368]

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[364] *Family Gathering,* John Toll, 67-68; Ken Ford, 84-86; Daniel Sperber, 144; Dieter Brill, 164-165; Fred K. Manasse 258-259; Larry Shepley, 300; Kip Thorne 306-310; Jacob Bekenstein, 423-424.
[365] See Charles Misner, Kip S. Thorne and John Archibald Wheeler, *Gravitation* (San Francisco, W. H. Freeman, 1973). This 1259 page opus continues to be the defining work on relativistic gravity.
[366] *Family Gathering,* Kip S. Thorne, 309.
[367] In a sense, this avenue of inquiry affirmed the well-known Wheelerism; “The right question is more important than the right answer.”
[368] *Family Gathering,* Cheuk-Yin Wong, 287.

On 25 October 2005, Professor Wong sent an email that listed six areas in which John Wheeler made lasting contributions to the lives and careers of his students. While Wong's 2005 correspondence was more analytical than his letter of 1976, it is no less laudatory.[369] The same can be said of more recent communications from John S. Toll, Charles Misner, Jacob Bekenstein, Peter Vajk, and Robert Fuller among others.[370] Dan Holz, John Wheeler's last advisee of record, summarized his socialization in physics as follows:

> It is a pleasure to acknowledge the tremendous support and encouragement given to me by John A. Wheeler. Over the last two years he has introduced me to the world of physics research and shaped the way I think about physics. I have benefited greatly, both as a physicist and as a person, from his example, and will carry this with me always. John Wheeler has had a profound impact on my life and I am deeply indebted.[371]

But is *anybody* really that good? It seems appropriate here to insert a disclaimer.

A large portion of the primary source material for this study has come from transcripts of interviews as well as correspondence with former Wheeler students and colleagues. I have also conducted an extensive examination of acknowledgements in hundreds of theses, dissertations, and documents included in various Wheeler festschrifts (esp. *Family Gathering*). By their very

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[369] Cheuk-Yin Wong, email to author (25 Oct 2005).

[370] Emails to the author from Robert Fuller (01 Sep 2005), Charles Misner (01 Sep 2005), Jacob Bekenstein (16 Sept 2005), Peter Vajk (21 Sep 2005), and John S. Toll (20 Feb 2006).

[371] Daniel E. Holz, "Primal Chaos Black Holes" (Senior Thesis, Princeton University, 1992), n.p. PRIN. Used by permission of the Princeton University Library.

nature, such source material can be characterized by a benign myopia in which the subject's faults lay outside the author's field of vision.

While John Wheeler was widely admired, that admiration was never universal. Unfortunately, the task of presenting a balanced picture is complicated by the circumstance that those students who were not successful under a particular mentor are seldom part of the historical record. There are no theses from which to glean acknowledgements. The unsuccessful students are not asked to contribute to festschrifts, nor are they likely to be interviewed by biographers.

Colleagues, including those former students who have achieved professional parity, are sometimes more candid in their evaluation of conduct outside the mentoring process. For example, Kip Thorne, once a student, and later a close friend and admirer of John Wheeler, has noted his strong disagreement with Wheeler in the matter of the Edward Teller and Robert Oppenheimer controversy.[372] Ken Ford has mentioned that, on occasion, Wheeler's determination to evaluate all sides of an issue made Marvin

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[372] Thorne, *Black Holes and Time Warps,* 235. The night before his testimony before the Atomic Energy Commission (28 April 1954), Teller came to Wheeler's hotel room in Washington, DC (Wheeler was in Washington on separate business and not involved in the hearings) and expressed his [Teller's] misgivings about the impact of his testimony on Oppenheimer's career. Wheeler told Teller that he should be guided by his integrity and tell the whole truth as he saw it. See also Wheeler and Ford, *Geons,* 201-202. Wheeler's version of events largely matches Thorne's, although Wheeler sees Teller as the martyr rather than Oppenheimer. Wheeler's reasoning is that Teller knew he was putting nearly all of his professional relationships at risk, and yet he chose to tell the truth as he saw it.

Goldberger (a former Princeton colleague and president emeritus of Caltech) want to "wring his [Wheeler's] neck."[373] Bryce DeWitt, a colleague of Wheeler at Texas, felt strongly that, Wheeler had done his former student Hugh Everett III a "scandalous" disservice by failing to support him in the face of criticism from Bohr and his followers over Everett's 'Many Worlds' thesis. After all, DeWitt reasoned, Everett's thesis had been written under Wheeler's supervision.[374] That said, the consensus of those who have spoken to the issue is that John Wheeler's faults were for the most part, subtle and benign in nature; perhaps even relatively few in number, but present nonetheless.

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[373] Telephone conversation between Ken Ford and the author (03 May 2006). Goldberger's frustration with Wheeler is also captured in Finn Aaserud, "Sputnik and the 'Princeton Three:' The National Security Laboratory that was not Meant to Be," *Historical Studies in the Physical and Biological Sciences* 25 no. 2 (1995): 185-240, 219. The context of Goldberger's irritation was that he, Wheeler, and Princeton economist Oskar Morgenstern had, in the wake of Sputnik, concluded that the United States needed a National Security Laboratory. The new lab would be located at Princeton. The difficulty was that none of the three men wanted to serve as director of the lab (a position that would require them to abandon their academic career for the two to three years it would take to get the lab up to speed). In a letter to their Princeton colleague Eugene Wigner, Goldberger expressed his disappointment in Wheeler: "I was induced to go back to Washington for a day after you left as perhaps you heard. John and Oskar worked on me to take the job; I worked on John in turn. Nobody yielded. I must say, however, that my reservations about John's being director, which I'm sure you sensed from our earlier discussions, were reinforced by seeing him in action as a leader. He has many great virtues and his halo is the finest gold. There is however an amorphous quality about him both in his reception of ideas and in his transmission of information to others. I find myself wanting to shake him to make him say something straight out and incisively. I have difficulty in putting this idea into words, but Oskar described his own feelings to me in a similar way."

[374] Bryce DeWitt and Cecile DeWitt-Morette interview with Kenneth W. Ford, 29 Feb 1995, Austin, TX, transcript, 6-7, NBL-AIP.

Section 3.7 Review

This chapter has examined the mentoring skill of John Wheeler as seen through the eyes of his students. In particular, the chapter addressed six questions: If Wheeler saw Bohr more as a collaborator than a mentor (presumably Breit and Herzfeld were also seen in this light), how did he see himself in relation to his own students? How did Wheeler's students see themselves in relation to him? Were there aspects of Wheeler's style of doing physics that Wheeler's former students consciously transmit (or transmitted) to their intellectual progeny? If so, what were they? Finally, as their own research and mentoring careers wind down, have the assessments of Wheeler's students changed between 1977 and 2008? If so, how?

Consciously or not, John Wheeler synthesized the best attributes of Herzfeld, Breit, and Bohr into a mentoring style of his own. Wheeler's students report that he unfailingly treated them, and indeed all whom he encountered, with courtesy and respect; he communicated an uncommon and inspiring enthusiasm for physics; he inculcated both mathematical craftsmanship and anschaulich conceptualization such that his students could 'extract the physics from the mathematics' for their own students. Beyond the physics, Wheeler's

students have indicated that his concern for their welfare, personal as well as professional, was second to none.[375]

John R. Klauder, editor of an earlier Wheeler festschrift volume (*Magic Without Magic*), summed the prevalent attitude of Wheeler's apprentices: “I have never met a Wheeler product who didn't speak warmly of his experience—and I never expect to.”[376]

[375] See *Family Gathering,* Gilbert Plass, 34; John S. Toll, 67; Kenneth W. Ford, 84; James J. Griffin, 103; Dieter Brill, 164; B. Kent Harrison, 182; John R. Klauder, 190; Fred K. Manasse, 258; Andris Suna, 283; Robert Geroch, 351; James York, 366; Jacob Bekenstein, 423; Bahram Mashoon, 429; J. R. Hugh Dempster, 489; S. Fred Singer, 516; Frank Zerilli, 533.

[376] John R. Klauder, ed., *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday* (San Francisco: W. H. Freeman, 1972); The quotation is from *Family Gathering,* John R. Klauder, 191.

Chapter Four: Mentoring in Modern Physics: Measuring the Efficacy of a Mentor

Section 4.1 Overview

In the previous chapter, I focused on qualitative aspects of mentoring with specific emphasis on the transfer of research attitudes and methods along a 'chain of wisdom' from the physicists who mentored John Wheeler, through Wheeler himself, and on to Wheeler's intellectual progeny. In contrast to Chapter Three, this chapter will, for the most part, be concerned with the quantitative means by which a given mentor's proficiency may be evaluated. Stated alternatively, whereas the previous chapter analyzed the mentoring attitudes and practices of John Wheeler in relation to the attitudes and practices employed by his mentors, this chapter will focus on a quantitative analysis of the outcomes of Wheeler's mentoring in relation to the mentoring outcomes of his peers.

That said, section two of this chapter, which details the insights made available through content analysis of the acknowledgements included in the dissertations, Master's Theses, and Senior Theses submitted during John Wheeler's tenure at Princeton and the University of Texas is, like Chapter Three, qualitative in nature. The quantitative examination of John Wheeler's mentorship begins in section three of this chapter where David Goodstein's 1993 study of Ph.D. production is used to calibrate Wheeler's mentoring career in terms of the number Ph.D. dissertations that he supervised. From

that point, I go on to develop the quantitative criteria by which Wheeler's mentorship can be compared to that of his colleagues. Sections four and five are the products of tabulating the publication records of those physicists who had earned their doctorate under the supervision of John Wheeler or under the supervision of one of his colleagues at either Princeton or the University of Texas. Section six offers the reader a brief review of the major points of this chapter as they relate to the dissertation as a whole.

Section 4.2 Insights into the Mentoring Relationship: Content Analysis of Dissertation and Thesis Acknowledgements

As stated in the introduction to this dissertation, in order to develop a census of John Wheeler's students, it was necessary to analyze the content of acknowledgements found in the dissertations, Master's Theses, and Senior Theses submitted to the physics departments at Princeton and the University of Texas during John Wheeler's tenure at those institutions. As it turns out, this content analysis was a particularly fruitful—if somewhat laborious—avenue of research.

To anyone who has even a passing familiarity with dissertation writing styles, it will come as no surprise that the vast majority of acknowledgements were of a *pro-forma* nature (e.g. 'I would like to thank Professor Dutton for suggesting this problem and for his/her continued advice.'). A somewhat smaller subset of acknowledgements offered more specific expressions of appreciation (e.g. 'I want to thank Professor Dutton for suggesting the

problem, for his/her continued advice throughout the project and for his/her timely and insightful suggestion that assisted in the completion of Chapter xyz.’).

There were an even smaller number of acknowledgements in which a student recalled his/her mentor guiding them through a particularly difficult part of the process (e.g. I especially want to thank Professor Dutton for suggesting the problem, and for his/her enthusiastic encouragement, particularly when a number of complicating factors coalesced such that the completion of this project appeared doubtful.’). While these ‘dark night of the soul’ expressions of gratitude are often compelling, they pale in comparison to some even more weighty testimonials.

These sober pronouncements were very rare, and they signified that a student was cognizant that a deep and profound understanding of the craftsmanship of science had been conveyed to him or her by a skilful and conscientious mentor. Such affirmations typically took one of the following forms: ‘Thanks to Professor Dutton, I now know what it means to be a professional physicist,’ or ‘I want to thank professor Dutton for providing me a wonderful example of how physics should be done.’ One of the more persuasive findings of this project was that no professor at Princeton and only one professor at Texas received more of these superlative testimonials than John Wheeler.

Two examples of this sort of emotive proclamation (i.e. ‘I now know what it means to be a physicist’) may be illustrative here. Demetrios Christodoulou, a Wheeler student who earned his Ph.D. from Princeton in 1971, acknowledged the impact of John Wheeler’s mentoring as follows:

> I can find no words in the English language adequate to express my gratitude to my advisor, Prof. John A. Wheeler. Without him, I would be sitting at this moment in a crowded sophomore classroom with two or three hundred students packed like sardines, and listening to a professor saying ‘recently the student Planck ...’. He picked me from the 11th grade of a Greek High School and made me a graduate student of the Physics Department of this University. When I came to Princeton I was not completely ignorant, but my knowledge resembled little pieces of wood wandering in a sea of mystery. He taught me what physics really is. From his own example I learned also how a real physicist should be. To him goes my deepest admiration.[377]

Fifteen years later, Warner A. Miller, a 1986 Ph.D. student at the University of Texas summarized his experience of being John Wheeler’s apprentice in these words:

> I wish to express my sincere thanks to my friend and advisor John Archibald Wheeler for the absolutely wonderful research environment he provided for me and my fellow colleagues -- The Center for Theoretical Physics at the University of Texas at Austin. Perhaps the most influential feature of our collaboration was the daily interaction we had in his car on the way to and from the university. Null-strut geometrodynamics was, in a large part, molded and created this way. My communication skills were likewise sharpened. I thank him for this also (The lesson - - Clear Communication!). Our interaction was not one of student to teacher, but rather student-teacher to student-teacher. Now that I have graduated, I can appreciate, more than ever before, our stimulating research collaboration. John Wheeler has helped

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[377] Demetrios Christodoulou, “Investigations in Gravitational Collapse and the Physics of Black Holes,” Ph.D. Dissertation, Princeton University, 1971.

> open my eyes to the world of knowledge. Thank you, John Wheeler.[378]

Clearly, John Wheeler inspired personal devotion and professional dedication in a number of his students. It should be noted however, that even the content of less moving dissertation acknowledgements can provide insight into the mentoring relationship. These insights, in turn, augment the statistical analysis that follows later in this chapter.

Beyond insight into the mentoring relationship, acknowledgement analysis can also offer a sense of the environment in which mentors and apprentices interact. In particular, the acknowledgment analysis revealed a significant number of cases when professors other than the advisor of record were acknowledged. To be clear, this circumstance is not terribly surprising in experimental physics where groups of faculty members and graduate students often collaborate on a single experiment or a group of closely related experiments that rely on shared apparatus. The surprising element was how often non-advisers to theoretical projects were acknowledged. For example, eightteen Princeton Ph.D. students, who were not John Wheeler's advisees, nonetheless felt compelled to acknowledge his contribution to their dissertation. Indeed, some of the most heartfelt expressions of gratitude received by John Wheeler, came from students with which he had no formal advising relationship. Here too, an example may prove useful. It may be

[378] Warner A. Miller, "Foundations of Null-Strut Geometrodynamics," Ph.D. Dissertation, University of Texas at Austin, 1986.

recalled from the previous chapter that William K. Wooters submitted his Ph.D. dissertation to the University of Texas at Austin in 1980. Although Wooters' advisor of record was Professor Linda E. Reichl, it is clear from the acknowledgement in his dissertation that John Wheeler had made important contributions as well:

> I would like to express my sincere thanks to two teachers – Professors L. E. Reichl and John A. Wheeler – whose encouragement was as responsible as anything else for the completion of this work. Professor Reichl not only gave me the opportunity to study the problem of the acquisition of information, but also kept me consistently on the right track, even during those times when I might otherwise have given up.… Professor Wheeler, having awakened my interest in the foundations of quantum mechanics, generously gave much of his valuable time to discuss with me the problems and prospects of physics at its most fundamental level, and transferred to me his belief that the hardest problems can yet be solved.[379]

Beyond the obvious utility of acknowledgement analysis in mentor identification, the above examples demonstrate that this approach can offer valuable insights into the nature of a given mentoring relationship. Moreover, this last example demonstrates that content analysis of dissertation acknowledgements may also provide a sense of the extent to which individual professors engage in—or individual physics departments promote—a collaborative atmosphere. In sum the content analysis of acknowledgements

[379] Wooters, "The Acquisition of Information from Quantum Measurements," Ph.D. dissertation, University of Texas at Austin, 1980. It may be recalled that a shorter version of this passage from Wooters 1980 Ph.D. dissertation was quoted in the previous chapter as an example of how a philosophical approach to physics (i.e. 'the hardest problems can yet be solved') is often transmitted from mentor to apprentice, in this case from Herzfeld to Wheeler to Wooters, along a chain of wisdom.

in dissertations and theses was a very fruitful avenue of research that provided a qualitative texture to the quantitative analysis described below.

Section 4.3 Mentoring Efficacy By the Numbers: Choosing Measures of Efficacy in Mentoring

The testimonials recounted above and in the preceding chapters make clear that many of Wheeler's former students became lifelong admirers. Then again, John Wheeler had a number of illustrious colleagues, and it stands to reason that those colleagues had many admirers among their former students as well. So, what set John Wheeler apart?

One prominent quality that makes John Wheeler unique among mentors is the quantity of his students. As reported in Chapter One, David Goodstein, Vice Provost of Caltech, has observed that a typical professor of physics can be expected to 'produce' fifteen doctorates in physics over the course of his or her career.[380] Over the course of John Wheeler's career however, he supervised the dissertations of fifty-one Ph.D.s and co-supervised

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[380] David L. Goodstein, "Scientific Ph.D. problems," *American Scholar* 62, no.2 (Spr 1993): 215-221, http://0-search.epnet.com.oasis.oregonstate.edu:80/login.aspx?direct=true&db=aph&an=9304060251 (05 Jan 2006), 217.

the dissertations of five others.[381] In other words, John Wheeler exceeded the average Ph.D. production by more than three-fold.

Although Wheeler often spoke enthusiastically about teaching (The famous Wheeler quip, “Universities have students to teach the professors,” may be recalled here), the extent to which he committed himself to mentoring of junior scholars was not apparent until I was able to perform content analysis on the manuscript holdings at Princeton and Texas.[382] At Princeton, for example, as mentioned earlier in Chapter Three, Wheeler supervised forty-three Senior Theses, two of which were from students outside the physics department.[383] Additionally, there were five instances when Wheeler served as a co-supervisor, and at least two other occasions where, based on the content of the acknowledgements, Wheeler served as a de-facto advisor or co-advisor to an undergraduate student.[384] As it stands, counting only the forty-three

[381] This census is based on a survey of 555 Ph.D. dissertations submitted to Princeton University and 389 Ph.D. dissertations submitted to the University of Texas at Austin during John Wheeler’s tenure at these institutions. This total also includes Katherine Way, who received her Ph.D. under John Wheeler’s supervision at the University of North Carolina.
[382] Wheeler interview with Ford, transcript, 1209, 1906, 2318; see also Wheeler and Ford, *Geons,* 150.
[383] Cooper, Duncan L Cooper, “Variational Properties of Chern’s Invariant Differential Forms,” Senior Thesis [Department of Mathematics], Princeton University, 1965; Charles Patton, “The Logical Microstructure of Physical Systems,” Senior Thesis [Department of Mathematics], Princeton University, 1972.
[384] Brit B. Katzen, “The Search for Pregeometry: The Work of John Archibald Wheeler,” Senior Thesis [Department of History], Princeton University, 1998, 60; Carl S. Rapp, “A Study of the Modern Concept of Limited Warfare,” Senior

Senior Theses for which John Wheeler was the advisor of record, he supervised more than twice as many Senior Theses as any other member of the Princeton Physics faculty. Moreover, in stark contrast to other senior faculty, Wheeler supervised all but three of the forty-three Senior Theses after he had become a full professor. Archival research at the University of Texas yielded similar results in that only two professors in the Texas physics department supervised more Master's Theses than did Wheeler. Here, it bears noting that Wheeler was in the twilight of career when he began his appointment at the University of Texas. Wheeler's heavy involvement in mentoring (as compared to his colleagues at Princeton and Texas) is illustrated in the tables below.

Thesis [Department of Politics], Princeton University, 1959, iii. Note: the Rapp thesis was found in UT-JAW.

Table 4.1 Ph.D. Dissertations and Senior Theses Supervised at Princeton

Professor	Total Ph.D.s Supervised	Ph.D. Students per Year	Contribution of Non-Advisor to Dissertation Acknowledged	Senior Theses Supervised[385]
J. A. Wheeler	46	1.15	19	43
T. R. Carver	16	0.76	13	21
R. H. Dicke	25	0.80	8	11
V. L. Fitch	15	0.71	5	5
M. L. Goldberger	19	0.95	10	4
R. Sherr	14	0.45	17	11
S. B. Trieman	24	1.02	16	4
A. S. Wightman	24	0.93	14	11
E. P. Wigner	25	0.83	16	0
P. U. Physics Department (105 Faculty)	555	0.13	N/A	669

Table 4.1 Ph.D.s and Senior Theses Supervised at Princeton, 1938-1978, 1988-1994. The ten professors selected are those who supervised the most Ph.D. dissertations in the 1938-1978 time frame. The column "Contribution of Non-Advisor to Dissertation Acknowledged" refers to cases in which a professor other than the advisor of record is acknowledged. Wheeler's enthusiasm for working with students is evidenced by the total number of dissertations supervised, the number of occasions in which he is acknowledged and the number of Senior Theses he supervised. As a case in point of intellectual lineage, Arthur S. Wightman is himself a former Wheeler Ph.D. student.

[385] While Princeton did offer a Master's degree in Physics, there was no requirement for a thesis to be submitted. See Princeton University Catalogue 1937-1938 (p324), PRIN; This regulation remained in effect throughout Wheeler's tenure at Princeton.

Table 4.2 Ph.D. and Master's Thesis Supervision at Texas, 1976-1990[386]

Professor	Total Ph.D.s Supervised	Ph.D. Students per Year	Contribution of Non-Advisor to Dissertation Acknowledged	Master's Theses Supervised
J. A. Wheeler	4	0.4	9	6
R. D. Bengston	13	1.08	17	7
B. S. DeWitt	11	0.92	11	0
D. A. Dicus	9	0.75	7	0
J. L. Erskine	10	0.83	6	6
M. Fink	9	0.75	21	11
R. A. Matzner	17	1.42	10	2
C. F. Moore	10	0.83	4	4
W. C. Schieve	10	0.83	9	1
L. C. Shepley	9	0.75	13	2
J. C. Thompson	12	1.00	12	7
U.T. Physics Dept. (97 Faculty)	389	0.33	N/A	122

Table 4.2 Ph.D.s and Master's Theses Supervised at the University of Texas at Austin, 1976-1990. The selected Professors, other than John Wheeler, are those who supervised the largest number of Ph.D. dissertations in the time frame 1976 – 1990. The column "Contribution of Non-Advisor to Dissertation Acknowledged" refers to cases in which a professor other than the advisor of record is acknowledged. As two cases in point of intellectual lineage, I note here that Lawrence C. Shepley was a Wheeler Ph.D. student at Princeton and Richard A. Matzner is an intellectual grandson of Wheeler through Charles W. Misner.

[386] Despite retiring from Texas in 1986, Wheeler continued to work with at least two students who listed John Wheeler as their supervising professor on dissertations that were submitted in 1990.

Even though Wheeler supervised fewer students per year than the colleagues listed in Table 4.2, his numbers compare favorably with the department as a whole. Moreover, it should be noted that John Wheeler was sixty-five years old when he began his tenure at Texas and seventy-five years old when he returned to Princeton as an emeritus professor of physics. Of course there is more to mentoring than having large numbers of students—even large numbers of former students who sing the praises of their former mentor. How then, can we objectively measure a given mentor's efficacy? "By their fruits, you shall know them."[387]

Section 4.4 Assessing Mentoring Efficacy Through Students' Scientific Productivity

The sociologist Harriet Zuckerman found that one prominent trait of the scientific elite is their tremendous scientific productivity.[388] In the context of Zuckerman's findings, it should not be surprising that the publication record of former Wheeler students was, for the most part, more robust than the publication record of those students mentored by Wheeler's colleagues. Two metrics, scientific productivity and disciplinary significance (as measured by citation count) were employed in making this evaluation.

Obviously, the total number of publications submitted is a function (among other considerations) of the length of a career. A standard expectation

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[387] Mathew 7:16, *World English Bible.*
[388] Zuckerman, *Scientific Elite,* 37, 62,146.

among research physicists seems to be two publications per year. If we presume a thirty-five year career (i.e. a doctorate awarded at age thirty and retirement at age sixty-five), than one can estimate that, on average, a professional researcher will produce something on the order of seventy publications. Of course, not all former students become researchers or remain active in physics research. Some move into disciplines other than physics (e.g. Wheeler's undergraduate advisee, Michael Stern), others move to administrative positions (e.g. Wheeler Ph.D. student John S. Toll), and still others perform defense related research that is not available to general researchers for citation (e.g. Wheeler Ph.D. student, Hugh Everett, III).[389]

In light of the foregoing, I chose to take one hundred publications as a benchmark for high scientific productivity over the course of a career (Wheeler himself has 396 publications to his credit), while fifty publications are considered a threshold for high productivity at the midpoint of a career. For the purposes of comparing Wheeler's former students with that of his colleagues, I developed a "Student Productivity Index", which is the percentage of former students who are credited with a benchmark level of publications.

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[389] Michael Stern, personal communication with author, 17 Oct 2007; for John Toll, see Wheeler and Ford, *Geons,* 101; for Everett see Peter Byrne, "The Many Worlds of Hugh Everett." Scientific American 297, no. 6 (Dec 2007), 98, http://proxy.library.oregonstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=27431241&loginpage=Login.asp&site=ehost-live (23 Feb 2009).

At this point in time (Winter 2009), the majority of students who studied under Wheeler and his colleagues at Princeton are currently either retired or in the later stages of their career. Therefore the benchmark for high productivity for Wheeler's Princeton students was set at one hundred publications. By contrast, a number of Wheeler's Texas students are just now passing the midpoint of their careers so that, for that population, fifty publications is taken as the threshold of high scientific productivity. The problem is to find an expeditious means documenting scientific productivity. Fortunately, this project has profited from the availability of online searchable databases such as Google Scholar, the ISI Web of Knowledge (the cyber-version of Science Citation Index), and the SLAC-SPIRES High Energy Physics (HEP) database. Here, a discussion of all three databases is in order.

Both Google Scholar and SLAC-SPIRES offer convenience. There is no charge for individual access, and a user need not be affiliated with a subscribing institution. And yet, for all their convenience, each of these databases has shortcomings. The difficulty with SLAC-SPIRES is that, as the name suggests, the focus of the database is on High Energy Physics, which serves to exclude a broad spectrum of research. Given that John Wheeler and—more to the point—his students engaged in research that ranged from nuclear/particle physics to general relativity/ cosmology to the interface of quantum mechanics and information theory, the narrow focus of SLAC-

SPIRES effectively disqualified the HEP literature database for use in this dissertation.

Google Scholar has the opposite problem of the SLAC-SPIRES HEP literature database in that it is somewhat too inclusive. This inclusivity is manifested in a mysterious and poorly understood redundancy. For example, a Google Scholar search for publications authored by “JA Wheeler” yields some 895 results.[390] Given that there are only 396 entries in John Wheeler’s personal bibliography, the Google Scholar data would seem to be of limited usefulness. A mitigating factor is that Google Scholar seems to be similarly redundant for all author searches. Therefore, as an instrument to measure scientific productivity, Google Scholar seems to be useful as a relative indicator or, more charitably, as a first order approximation.

Of course, the optimum resource for citation data is the *Science Citation Index*. Here again, there are serious difficulties with this source. Until quite recently, the *Science Citation Index* existed in three separate media formats: print, CD-ROM, and the online ISI Web of Knowledge. The foremost complication was that these formats did not overlap in time, and worse, the web-based ISI Web of Knowledge database did not extend back in time before 1970. Given that the post 1970 time frame misses much of John Wheeler’s

[390] search author “JA Wheeler,” http://scholar.google.com/scholar?as_q=&num=100&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JA+Wheeler%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= (23 Nov 2008).

career, and that the CD-ROM and print versions were not—indeed are not—accessible to those of us who are visually impaired (e.g. this author), the Science Citation Index, like the SLAC-SPIRES database was, regrettably, unsuitable for the research at hand.

Thus, despite its less than desirable redundancy issues, at the time this project was undertaken, Google Scholar was the only database available to the author that was comprehensive in terms of a broad spectrum of physics publications and inclusive of the requisite time frame. Fortunately, future scholars will benefit from a recently released and somewhat more robust ISI database (i.e. one that extends back in time to 1900). At the time of this writing however (Winter 2009), Oregon State University was not yet a subscriber to the newer version of the ISI database. With the foregoing stipulations in hand, the methodology supporting these Student Productivity Indices and the comparison of these indices for John Wheeler and his colleagues are included in the following section.

Broadly speaking, the physicists who completed their Ph.D. at Princeton demonstrated a higher rate of productivity than those who trained at Texas. As a matter of course in assessing mentoring outcomes, a researcher should consider whether a particular trait is characteristic of an institution or an individual mentor. In the case of scientific productivity, it appears that on an institutional basis, the ethos of scientific productivity was—and perhaps is—inculcated to a higher degree in Princeton than it is at Texas. In both cases, as

compared with the former students of his colleagues, John Wheeler's former students demonstrated an average level of scientific productivity. A Google Scholar survey of former Wheeler Ph.D. students from Princeton indicates that fifteen out of Wheeler's forty-six Ph.D. students (34.8%) have more than 100 publications. In other words, for his Princeton years, Wheeler had a Student Productivity Index of 34.8%. Among Princeton physics professors, Wheeler ranked fourth in Student Productivity behind Val Fitch (46.6%), Sam Trieman (41.7%) and Ruby Sherr (35.7%). It should be noted from Table 4.1 however, that each of these professors had a comparatively small numbers of students. With fifteen and fourteen students respectively, Val Fitch and Ruby Sherr each supervised fewer than one-third of the number of Ph.D. students supervised by Wheeler. Similarly, Sam Trieman's twenty-five Ph.D. students is slightly more than half the number supervised by Wheeler at Princeton.

Then too, it may be recalled from the Introduction as well as Chapters One and Two that John Wheeler was extensively involved in defense related research and consulting. A prime example of the depth of Wheeler's involvement in defense work is his effort to establish a National Security Laboratory (a predecessor to Project JASON) at Princeton.[391] Thus, it is not

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[391] Finn Aaserud, "Sputnik and the 'Princeton Three': The National Security Laboratory that was not Meant to Be," *Historical Studies in the Physical and Biological Sciences* 25 no. 2 (1995), 185-240; See also extensive correspondence between Wheeler and defense contractors (e.g. Rand, Convair, Dupont) at UT-JAW; See also "Anti-Ballistic Missile System Notes, 1969," Box 9.7/2008-164/20, UT-JAW; See also "Defense Studies" (3 vol.

surprising that, as we see from the letters and curricula vitae submitted to *Family Gathering,* a relatively large number (i.e. 15%) of Wheeler's Princeton students (e.g. David M. Chase, Robert Euwema, Hugh Everett III, Brendan Godfrey, Clifford Rhoades, S. Fred Singer, and Frank J. Zerilli) spent all or significant portions of their career in defense related research.[392] Therefore, it is likely that a high percentage of the research conducted by those former apprentices was (or is) classified, and thus not available for general circulation. If those publication records were available in their entirety, it is probable that Wheeler's Student Productivity Index for his Princeton years would have ranked higher among his colleagues. Wheeler's Student Productivity Index (based on a benchmark of fifty publications) for his Texas years, also ranks fourth among those colleagues who were closest to Wheeler in rate of Ph.D. production. That said, a combined Student Productivity Index (i.e. one that considered both Wheeler's Princeton and Texas students) would place Wheeler slightly ahead of William Schieve with 32% of his students achieving the 100 publication threshold. Wheeler would also lead the Texas department with 48% of his students achieving the fifty publication threshold.

1955-1958; 1959-1962; 1963-1968), UT-JAW; Wheeler and Ford, *Geons,* 271-288; See also Wheeler correspondence regarding Advisory Group on Scientific Manpower, Senator Henry M. ("Scoop") Jackson Papers, Accession No. 3560-003, Box 251, UW-HMJ.

[392] See *Family Gathering* for curricula vitae of Chase, Euwema, Godfrey, Rhoades, Singer, and Zerilli; See also Byrne, "The Many Worlds of Hugh Everett," 98; these seven former Wheeler apprentices amount to 15% of Wheeler's total of forty-six Ph.D. advisees at Princeton.

Table 4.3 Student Productivity Index – Selected Professors at Princeton

Professor	Number of Ph.D. Students	Students with 100+ Publications	% of Ph.D. Students	Students with 50+ Publications	% of Ph.D. Students
J. A. Wheeler	46	16	34.8%	23	50.0%
T. R. Carver	16	1	6.3%	3	18.7%
R. H. Dicke	25	7	28.0%	8	32.0%
V. L. Fitch	15	7	46.6%	9	60.0%
M. L. Goldberger	19	6	31.6%	7	36.8%
R. Sherr	14	5	35.7%	7	50.0%
S. B. Treiman	24	10	41.7%	12	50.0%
A. S. Wightman	24	6	25.0%	11	45.8%
E. P. Wigner	25	4	16.0%	10	40.0%

Table 4.3 Student Productivity Indices for Selected Professors at Princeton, 1938 – 1978. Although Wheeler ranks fourth among his colleagues, a relatively large portion of his students spent significant portions of their career in defense related research and consequently, many of the publications authored by those students was (or is) classified and therefore not available to the standard research journals used in accumulating this data.

Table 4.4 Student Productivity Index – Selected Professors at Texas

Professor	Number of Ph.D. Students	Students with 100+ Publications	% of Ph.D. Students	Students with 50+ Publications	% of Ph.D. Students
J. A. Wheeler	4	0	0%	1	25.0%
R. D. Bengston	13	2	15.4%	4	30.8%
B. S. DeWitt	11	0	0%	1	9.1%
D. A. Dicus	9	1	11.1%	4	44.4%
J. L. Erskine	10	0	0%	1	10.0%
M. Fink	9	1	11.1%	2	22.2%
R. A. Matzner	17	2	11.8%	4	23.5%
C. F. Moore	10	1	10.0%	3	30.0%
W. C. Schieve	10	3	30.0%	3	30.0%
L. C. Shepley	8	0	0%	1	12.5%
J. C. Thompson	13	0	0%	0	0%

Table 4.4 Student Productivity Index for Selected Professors at the University of Texas at Austin, 1976 – 1988. Here again it shout be noted that John Wheeler began his tenure at the University of Texas at the age of sixty-five. Nonetheless, the productivity of his students ranks fourth among his colleagues.

But scientific productivity is only one indication that a given mentor's students have established (or are establishing) distinguished careers. A perhaps more compelling marker is the significance or 'impact' of the research performed by a given mentor's former apprentices. The following section details how this data was extracted from available source material and applied to the project at hand.

Section 4.5 Assessing Efficacy Through the Impact of Students' Published Research

A second element of the quantitative analysis employed in this dissertation is the "Index of Students' Impact," which is the percentage of a given mentor's former students with one or more publications that have achieved a threshold level significance as determined by the number of times that particular publication has been cited in scientific research journals. In establishing this citation threshold, I have benefited from a very timely and insightful suggestion by Professor David Kaiser of MIT. In essence, this metric is an adaptation of the distribution curve of the SLAC-SPIRES database of High Energy Physics literature.[393] To be clear, I am employing the schematic organization of the SLAC-SPIRES HEP distribution curve, not the database itself nor the distribution curve derived from citations of HEP literature.

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[393] Stanford University, "SLAC-SPIRES HEP Database of Citation Distribution" (01 Dec 2005), http://www.slac.stanford.edu/spires/play/citedist/ (14 Jul 2008).

Here, the reader is well-served by a review of the characteristics of the SLAC-SPIRES HEP distribution curve. The SLAC-SPIRES database classifies publications as follows:

1) Those publications with 500 or more citations are categorized as “Renowned” and they represent approximately 0.34% of all the citeable papers in the High Energy Physics (HEP) database.
2) Those publications with 250 – 499 citations are categorized as “Famous” and they represent approximately 1.19% of all the citeable papers in the HEP database.
3) Those publications with 100 – 249 citations are categorized as “Very Well-Known” and they represent approximately 5.29% of all the citeable papers in the HEP database.
4) Those publications with 50 – 99 citations are categorized as “Well-Known” and they represent approximately 9.49% of all the citeable papers in the HEP database.
5) Those publications with 10 – 49 citations are categorized as “Known” and their approximate percentage of all the cited papers in the HEP database is not listed.
6) Those publications with 1 – 9 citations are categorized as “Less Known” and their approximate percentage of all the cited papers in the HEP database is not listed.
7) Those publications with 0 citations are categorized as unknown and their approximate percentage of all the cited papers in the HEP database is not listed.

I also note here that, in the breakdown of citation percentiles, SLAC-SPIRES includes an unnamed subset of the “Renowned” category that is limited to papers with 1000 or more citations. These represent approximately 0.12% of all the cited papers in the HEP database. As can be surmised, the vast majority—indeed 90% of all citeable papers in the HEP database—are cited fewer than fifty times. Also, as noted on the SLAC-SPIRES website, the category ‘sort bins’ are not cumulative (i.e. each publication is counted in

one—and only one—category).[394] Thus, a scientist who authors a paper that is cited 403 times is credited for a paper with 250 – 499 citations, but that same paper is not simultaneously credited in the 50 – 99 bin or the 100 – 249 bin. As noted at the outset of this section, the SLAC-SPIRES distribution categories and sort bins are derived from the literature on High Energy Physics. The question is whether though their usefulness can be extended beyond that subfield of physics.

A recent study of citation statistics of all papers in the *Physical Review*—covering all branches of basic physics research, not just High Energy Physics—found a remarkably similar distribution of citations.[395] Once again, fifty citations emerges as a useful and meaningful lower bound for indicating papers of special significance; and the distribution bins (50 – 99 citations; 100 – 249 citations, and so on) showed a similar pattern to the SLAC-SPIRES data. Thus, with the stipulations that are explained in the following paragraphs, I feel confident adopting a modified SLAC-SPIRES citation distribution curve and citation category bins for this study.

The first stipulation concerns the poorly understood redundancy issue in Google Scholar. As with the publication statistics, it appears that Google Scholar has something of a universal redundancy in the citation count for any

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[394] SLAC-SPIRES HEP Database of Citation Distribution" (01 Dec 2005).
[395] Sidney Redner, "Citation Statistics from 110 Years of *Physical Review*," *Physics Today* 58, No. 6 (Jun 2005), 49-54. I am indebted to Professor David Kaiser for alerting me to this source.

given publication. For example, in the case of John Wheeler, we see that as of 23 November 2008, the opus *Gravitation* (coauthored with former students Charles Misner and Kip Thorne) had been cited 2,723 times. Further down the search results webpage, we find instances when it appears that a particular chapter or section of *Gravitation* has been cited by some group of articles. This same redundancy was found in a number of ‘spot-checks’ involving well-known and not-so-well-known publications. Here again, as with the total number of publications, the data extracted from Google Scholar is taken to represent a relative rather than an absolute measure. Unfortunately, for the reasons detailed above, a relative measure will have to suffice for this dissertation.

Three other points need to be made regarding the “Index of Students’ Impact” metric. While the SLAC-SPIRES and Redner distribution curves suggest a lower bound of fifty citations as the threshold of significance in citation counts, the inherent redundancy in the Google Scholar database suggests modifying the significance threshold of fifty upwards to a threshold of 100. In other words, in order to be counted as a former student who produced significant publications, that student would have to be credited with a publication that had been cited at least one hundred times. It should be noted here that 100 citations is well within the ninetieth percentile in relation to citation counts for all published research in physics.

The second point is that, for reasons having to do with formatting the text in this dissertation, our tables have been truncated in comparison to the SLAC-SPIRES classification scheme. In particular, SLAC-SPIRES uses three separate categories to delineate publications that have been cited more than 100 times: “Renowned,” 500+ citations; “Famous,” 250 – 499 citations; “Very Well-Known,” 100 – 249 citations. I have chosen to combine the ‘Famous’ category (250 – 499 citations) and the ‘Very Well-Known’ category (100 – 249 citations into a “Very Well-Known” classification of papers with between 100 and 499 citations. Here, it bears reminding that even with Google Scholar’s redundancy issues, fewer than 10% of all research publications are cited 100 times or more.

Finally, unlike the SLAC-SPIRES HEP database, I have chosen to make the bins cumulative. In other words, a paper that is cited 508 times is counted for the author of that paper as both a ‘renowned’ and a ‘very well-known’ publication. The distinction comes from the fact that SLAC-SPIRES is assessing individual publications while this dissertation is using those publications to assess the significance of the science performed by a given physicist. Stated alternatively, SLAC-SPIRES is concerned with publications and we are concerned with physicists. Thus for SLAC-SPIRES, individual papers are classified as renowned or very well-known—but not both. Whereas for our purposes, a physicist who publishes a renowned paper is also given credit for publishing a very well-known paper. With the foregoing stipulations in

mind, the tables comparing the Index of Students' Impact for Wheeler and selected colleagues are shown below.

Table 4.5 Index of Students' Impact for Selected Mentors at Princeton

Professor	Number of Ph.D. Students	Students with 'Renowned' Publications having 500+ Citations	% of Ph.D. Students	Students with 'Very Well-Known' Publications having 100 - 499 Citations	% of Ph.D. Students
J. A. Wheeler	46	12	26.1%	29	63.0%
T. R. Carver	16	0	0%	2	12.5%
R. H. Dicke	25	3	12.0%	8	32.0%
V. L. Fitch	15	3	20.0%	5	33.3%
M. L. Goldberger	19	2	10.5%	6	31.6%
R. Sherr	14	0	0%	4	28.6%
S. B. Treiman	24	6	25.0%	11	45.8%
A. S. Wightman	24	2	8.3%	11	45.8%
E. P. Wigner	25	4	16.0%	13	52.0%

Table 4.5 The Impact of Students' Work for selected professors at Princeton. The relatively high percentage of students with 'renowned' or 'famous' publications to their credit is indicative of the strength of this department. This data also speaks to the mentoring proficiency of Val Fitch, Sam Treiman, Arthur Wightman (himself a former Wheeler student), Eugene Wigner, and Wheeler himself. Note, since this table is intended to assess the work of students rather than the impact of papers, the "Very Well-Known" column includes the work of those students who authored "Renowned" publications.

Table 4.6 Index of Students' Impact for Selected Mentors at Texas

Professor	Number of Ph.D. Students	Students with 'Renowned' having Publications 500+ Citations	% of Ph.D. Students	Students with 'Very Well-Known' Publications having 100 – 499 Citations	% of Ph.D. Students
J. A. Wheeler	4	0	0%	0	0%
R. D. Bengston	13	1	7.7%	2	14.4%
B. S. DeWitt	11	0	0%	1	9.1%
D. A. Dicus	9	1	11.1%	3	33.3%
J. L. Erskine	10	0	0%	0	0%
M. Fink	9	0	0%	1	11.1%
R. A. Matzner	17	0	0%	3	17.6%
C. F. Moore	10	0	0%	0	0%
W. C. Schieve	10	1	10.0%	3	30.0%
L. C. Shepley	8	0	0%	0	0%
J. C. Thompson	13	0	0%	0	0%

Table 4.6 The Impact of Students' Work for Selected Professors at Texas. As of Winter 2009, none of John Wheeler's Ph.D. students has authored a renowned publication. Note, as with Table 4.5 there is a redundancy in the "Renowned" and "Very Well-Known"columns. Note also that W H. Zurek, the former W. Schieve student with "Renowned" work, wrote at least one of the "Renowned" pieces as a post-doc with Wheeler.

The results of this analysis are striking. Some 42.8% of the students who earned a doctorate under the supervision of John Wheeler or one of his Princeton colleagues are credited with at least one publication that is ‘very well-known’ (i.e. cited more than 100 times). Indeed, 15.4% of the Princeton-trained physicists had authored or co-authored at least one ‘renowned’ publication (i.e. cited more than 500 times). The impact of those physicists who trained under Wheeler and his colleagues at Texas is somewhat less impressive. Of those physicists who earned their doctorate at the University of Texas during the timeframe 1976-1988, 10.5% are credited with a ‘very well-known’ publication and 2.6% have authored or co-authored a ‘renowned paper.

Again we face the question of whether mentoring efficacy is an institutional or an individual trait. In fact, the research presented here indicates that it is both.

Clearly, in contrast with Texas, the intellectual horsepower at Princeton (e.g. six current or future Nobelists were colleagues of Wheeler at Princeton) was a drawing card for the best students.[396] Even among that illustrious company however, Wheeler always seemed to stand out as a drawing card. Some examples come immediately to mind. Tom Griffy, who served as chair

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[396] During John Wheeler’s tenure at Princeton, the Physics faculty included six current or future Nobel Laureates: Eugene Wigner, Val Fitch, James Cronin, Philip Anderson, David Gross, and Frank Wilczek.

of the Texas physics department from 1974 to 1984, believed that having Wheeler aboard brought an enhanced "credibility" to the department, and without Wheeler on the faculty, Griffy doubts that he could have attracted Nobel Laureate Steven Weinberg from Harvard to Texas in 1982.[397] The timing is significant here. Unlike Wheeler, who had, at least nominally, retired from Princeton in 1976 at the age of sixty-five, Weinberg was only forty-nine and had been awarded the Nobel Prize just three years before he came to Texas.[398]

This was not the only time the physics department at Texas employed Wheeler as an attraction. Brice DeWitt and Cecile DeWitt-Morette, two of Wheeler's colleagues at Texas, credit Wheeler with bringing the eminent physicists Philip Candelas, David Deutsch, and his former student, Claudio Teitelboim (each of whom has multiple "Renowned" publications to their credit) to Texas. In another effort to strengthen the department, Wheeler organized several conferences (e.g. the "Tenth Texas Relativistic Astrophysics Symposium") that were aimed at potential graduate students whom the department saw as particularly promising. Participants received an all expenses paid trip to Austin where, in addition to the conference, they had

[397] Thomas Griffy, "Interview with Tom Griffy," interview by Ken Ford, 28 Feb 1995, University of Texas at Austin, transcript. http://www.aip.org/history/ohilist/23203.html (09 Oct 2008).
[398] Steven Weinberg, "Autobiography," http://nobelprize.org/nobel_prizes/physics/laureates/1979/weinberg-autobio.html (05 Mar 2009), also in *Nobel Lectures, Physics 1971 – 1980* (Singapore: World Scientific Publishing, 1992).

ample opportunity to interact with the physics faculty.[399] Indeed, Wheeler's potential to attract high caliber students and faculty was evident very early in his career. In March of 1942 (more than three years before Wheeler was offered tenure as an associate professor at Princeton), G. W. Stewart, the Dean of Faculty at the University of Iowa offered Wheeler the position of Dean of Iowa's graduate school.[400] In sum, although Princeton clearly had (and has) an institutional advantage in attracting high quality students and faculty, John Wheeler made a number of successful efforts at mitigating Texas' perceived shortcomings.

Setting institutional considerations aside, it can be seen in Table 4.5, that more than one in four of the physicists who apprenticed under John Wheeler during his Princeton years, has authored or co-authored at least one 'renowned' publication, and more than three in five authored or co-authored at least one 'very well-known' publication. Thus, for his Princeton students, John Wheeler is credited with an 'Index of Students' Impact' of 63%. It is worth noting here that only one of Wheeler's Princeton colleagues had an Index of Students' Impact that exceeded 50% and that professor (E. P. Wigner) had

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[399] Bryce DeWitt and Cecile DeWitt-Morette, "Interview with Bryce DeWitt and Cecile DeWitt-Morette," interview by Kenneth W. Ford, 28 Feb 1995 Austin, TX, transcript, NBL-AIP; see also "Final Program", Box 9.8/2008-164/33 (7), "Symposia 80 - 82." Folder [bound] "Texas Symposium 1980," UT-JAW.

[400] See, G. W. Stewart to John A. Wheeler, 08 Mar 1942, Box 34 "Correspondence," Folder "1942-1947," UT-JAW; See also "Physics Dept. Records" Box 4, Folder 4 "Trustees Decision to Promote Wheeler," PRIN-PHY.

slightly more than half the number of students mentored by Wheeler. Indeed, excluding Wheeler, the average Index of Students' Impact among Princeton Professors was 37%. But there is more to the story.

Here, let us recall the caveat regarding extensively shared authorship in experimental physics that was introduced in Chapter One. In particular, I cited the instance of Roger Kadel, a former apprentice of Nobelist and Wheeler colleague Val Fitch. While Kadel had been credited with authoring one "renowned" publication, it turns out that the publication in question listed 434 authors and was five pages in length.[401] But, Kadel is not an isolated case. Lawrence R. Sulak, another former Fitch apprentice, is credited with seven publications that have achieved 'renowned' status. On closer inspection however, we find that the articles for which Sulak is credited averaged less

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[401] R. W. Kadel et al [433 others], "Observation of Top Quark Production in $\bar{p}$ p Collisions with the Collider Detector at Fermilab", *Physical Review Letters* 74, No. 14 (3 Apr 1995), 2626-2631, http://prola.aps.org/abstract/PRL/v74/i14/p2626_1 (23 Nov 2008).

than five pages in length and featured an average of 82 authors.[402] A similar case could be made about the 'renowned' publication of David G. Cassel, another former student of Val Fitch.[403] Only one former Wheeler student, Kip Thorne, has any publication that is the product of extensively shared authorship (fourteen authors, eight pages), and that work, like the published research of Kadel, Sulak, and Cassel involved experimental research.[404] To be fair, all but two of the 'renowned' articles credited to Sulak were published in *Physical Review Letters* which has a strict editorial policy that limits the

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[402] Lawrence R. Sulak, et al [36 others], "Observation of a neutrino burst in coincidence with supernova 1987A in the Large Magellanic Cloud," *Physical Review Letters* 58, No 14 (06 Apr 1987), 1494-1496; Lawrence R. Sulak, et al [28 others], "Measurement of Atmospheric Neutrino Composition with the IMB-3 Detector," *Physical Review Letters* 66, no, 20 (20 May 1991), 2561-2564; Lawrence R. Sulak, et al [22 others], "Electron and Muon-Neutrino Content of the Atmospheric Flux," *Physical Review D* 46, No. 9 (01 Nov 1992), 3720-3724; Lawrence R. Sulak, et al [125 others], "Measurements of the Solar Neutrino Flux from Super-Kamiokande's First 300 Days," *Physical Review Letters* 81, No. 6 (10 Aug 1998), 1158-1162; Lawrence R. Sulak, et al [120 others], "Evidence for Oscillation of Atmospheric Neutrios," *Physical Review Letters* 81, No. 8 (24 Aug 1998), 1562-1567; Kamiokande Collaboration [Lawrence R. Sulak and 123 others], "Study of the Atmospheric Neutrino Flux in the Mult-GeV Energy Range," *Physics Letters B* 436, Nos. 1-2 (17 Sep 1998), 33-41; Lawrence R. Sulak, et al [118 others], "Solar ^{8}B and HEP Neutrino Measurements from 1258 Days of Super-Kamiokande Data," *Physical Review Letters* 86, No 25 (18 Jun 2001), 5651-5655.

[403] David G. Cassel, et al [173 others], "Evidence for Penguin-Diagram Decays: First Observation of B-->K*(892)γ," *Physical Review Letters* 71, No. 5 (02 Aug 1993), 674-678.

[404] Kip S. Thorne, et al [13 others], "LIGO: The Laser Interferometer Gravitational-Wave Observatory," *Science* 256, No. 5055 (17 Apr 1992), 325-333

number of pages in an article.[405] I should also note that Kip Thorne has three other 'renowned' publications that have no more than one or two co-authors.

The foregoing is not intended to diminish the accomplishments of these particular experimental physicists or—more to the point of this dissertation—their mentors. Rather the point is that extensively shared authorship offers, at best, an ambiguous measure of the efficacy of a mentor in terms of both the "Student Productivity Index and the "Index of Students' Impact." Thus, for the latter years of John Wheeler's career, it became increasingly difficult to gauge the efficacy of a mentor in experimental physics. That reservation aside, the publication data for the physicists who apprenticed at Princeton in the years 1938 – 1978 suggests the presence of an exceptional group of mentors, with John Wheeler foremost among them.

The mentoring outcomes (as measured by the 'Index of Students' Impact') at Texas tell a very different story. As of this writing (Winter 2009), none of Wheeler's Texas students has produced a "very well known" publication.

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[405] "About Physical Review Journals," http://publish.aps.org/about (01 Mar 2009) and "Notice to Referees," http://forms.aps.org/referee/rvwstndrds-pra.pdf (01 Mar 2009); *Physical Review Letters* was established in the late 1950s as a forum for "short, important papers" which can be published quickly (and therefore establish scientific priority). *Physical Review Letters* publishes Letters of not more than four journal pages and Comments of not more than one journal page. The journal is published weekly with typically one referee per letter or comment. The referees are encouraged to render a decision within one week of receiving the manuscript.

Here, it seems reasonable to presume that this discrepancy is due, at least in part, to the circumstance that Princeton was able to attract a higher caliber of student than Texas. Hence, it should not be surprising that only three of Wheeler's colleagues at Texas had, within the 1976 – 1988 timeframe, mentored students who authored or co-authored at least one 'renowned' publication and only six of the eleven included in our survey mentored students with at least one 'very well-known' publication. On closer inspection however, we see that John Wheeler had a hand in mentoring one of the more talented physicists that trained at Texas.

Wojciech H. Zurek, the student of William Schieve who is credited with having authored or coauthored six 'renowned' publications, was also a post-doctoral fellow under Wheeler at Texas in the years 1979 - 1981. Indeed, one of Zurek's renowned publications, *Quantum Theory and Measurement* (co-authored with Wheeler), came out of Zurek's post-doctoral work with Wheeler. Moreover, Zurek maintains that, in addition to the book, at least ten separate publications (including two 'renowned' and one 'very well-known paper) were inspired by his post-doctoral work with Wheeler.[406] Thus, it would appear that

[406] John Archibald Wheeler and Wojciech Hubert Zurek, *Quantum Theory and Measurement* (Princeton, NJ: Princeton University Press, 1984). As per Google Scholar, this book has been cited more than 700 times; As per Wojciech Zurek (personal communication with the author), 25 Feb 2009, ten of his papers were conceived and-or inspired during Zurek's post-doctoral fellowship with John Wheeler. Of these, two ("Pointer Basis of Quantum Apparatus: Into What Mixture Does the Wavepacket Collapse?," *Physical Review D* 24, No 5 (15 Sep 1981), 1516-1525; "Environment-Induced

even in an environment that was not awash with the ‘best and brightest’ students from across the nation, John Wheeler had significant success as a mentor.

Section 4.6 Review

In this chapter, I have demonstrated the insights available through content analysis of the acknowledgements of dissertations and theses. Furthermore, I have shown that content analysis can also offer a sense of the degree to which a given mentor collaborates with his or her peers, or a particular department promotes a collaborative environment.

That said, the key element in this chapter is the innovation and development of quantitative means by which the outcomes of a given mentor, or group of mentors (e.g. a physics department faculty) can be objectively evaluated. Here, as noted above, I have profited immensely from a timely and insightful suggestion by Professor David I. Kaiser of MIT. This technique, which is predicated on publication records of a given mentor’s former apprentices, enables a two-dimensional, complementary appraisal (i.e. scientific productivity and the significance of published research) of that mentor’s proficiency.

Superselection Rules,” *Physical Review D* 26, No. 8 (15 Oct 1982), 1862-1880) have been cited more than 500 times and one ([with W. K. Wootters] “Complementarity in the Double-Slit Experiment: Quantum Nonseparability and a Quantitative Statement of Bohr's Principle,” *Physical Review D* 19, No. 2 (15 Jan 1979), 473-484) has been cited more than 100 times.

In the Master's thesis, which preceded and formed the foundation for this project, the evaluation of John Wheeler's skill as a mentor was entirely subjective in that it relied exclusively on the recollections of Wheeler's former students. The quantitative analysis here makes it possible to substantiate—or disprove—the inference of those memories which are so often clouded and colored by time.

Moreover, these same methods can be applied to the other mentors and or institutions to enable an "apples-to-apples" comparison of mentoring outcomes such that department chairs or university administrators can identify proficient mentors within their ranks, take steps to emulate the strategy and practices employed by those mentors, and establish an intellectual environment that is conducive to effective mentoring.

Chapter Five: John Archibald Wheeler Considered in the Context of Research School Scholarship and the Scholarship of Pedagogy in Science

Section 5.1 Overview

“Scientists are not born, they are made.” So asserts historian David Kaiser of MIT in his edited volume *Pedagogy and the Practice of Science*.[407] The ‘making of scientists’ is, in fact, the focus for this dissertation. As a result of a preliminary investigation (i.e. the 2006 Master’s Thesis upon which this work is predicated) this project began with two objectives. One objective was to determine how best to situate the making of scientists, theoretical physicists in particular, in the existing problem set of scholarly literature. The second, and more significant objective was to develop a means by which it is possible to objectively assess the mentoring workmanship of those scientific craftsman who preside over the final stage of this making in the mentorship of scientists. This second objective was born of an aspiration to identify the most proficient mentors and to evaluate their most effective practices?

Previous chapters have focused on an overview of the historical literature dealing with research schools; a biographical sketch of John Archibald Wheeler with an eye to his career as a physicist and mentor; an assessment of Wheeler's expertise as a mentor as seen through the remarks

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[407] David Kaiser, ed., *Pedagogy and the Practice of Science*, Inside Technology Series, ed. Wiebe E. Bijker, W. Bernard Carlson, and Trevor Pinch (Cambridge, MA, MIT Press, 2005), 1.

of his former students; and a quantitative evaluation of Wheeler's mentoring outcomes as compared with the mentoring outcomes of his colleagues at Princeton and Texas.

In this chapter, I aim to synthesize what has been learned about the mentoring practices of John Wheeler with the generalized attributes of a successful research school and the emerging scholarship dealing with scientific pedagogy. I begin by revisiting the work of historian Gerald Geison, who established the comprehensive criteria that define a research school, and I then turn to recent work on pedagogy in physics, especially as developed by MIT historian David Kaiser. The ensuing sections of this chapter correlate specific aspects of the research school literature (e.g. charismatic leadership, ready access to publication, etc.) with the history of Wheeler's relationship with his students as well as evidence that Wheeler's former students have self-consciously incorporated a number of Wheeler's pedagogical methods into their own mentoring style. Finally, I conclude the chapter positing that John Wheeler is an exemplar of a Geison-Morrell research school, that mentors serve as instruments of pedagogy in theoretical physics, and that the study of scientific mentoring forms a link between those two areas of scholarly investigation.

Section 5.2 The Reference Frame of Research School Literature: John Archibald Wheeler as the 'Charismatic Director'

There is a considerable body of historical scholarship directed at research schools of the nineteenth and early twentieth centuries.[408] With the notable exceptions of an article by S. T. Keith and Paul K. Hoch, as well as a chapter in *The Cambridge History of Science,* by David E. Rowe, these research schools were based in laboratories or observational science.[409]

Similarly, there is a plethora of literature regarding the role of mentors and the process of mentoring emerged. By and large, these studies are unfocused in that they are intended to be applicable to a wide range of audiences and environments, from businessmen to civil servants, to educators, to self-help gurus and beyond.[410] A small percentage of these studies are directed at mentoring in science, and some of those are specific to mentoring women or minorities who might be embarking on – or even

[408] Op cite note 22, Chapter 1.
[409] S. T. Keith and Paul K. Hoch, "The Formation of a Research School: Theoretical Solid State Physics at Bristol, 1930–54," *British Journal for the History of Science* 19, Pt. 1, No. 6 (Mar 1986), 19–44; David E. Rowe, "Mathematical Schools, Communities and Networks," in *The Modern Physical and Mathematical Sciences,* ed. Mary Jo Nye, Vol. 5 of *The Cambridge History of Science,* General eds. David C. Lindberg and Ronald L. Numbers. (New York: Cambridge University Press, 2003), 113–132.
[410] Op cite note [56], Chapter 1.

considering – a career in science.[411] As is the case with the research school literature however, virtually all the studies that deal with mentoring in science are focused on those disciplines that are practiced in a laboratory. And yet, in all this, nary a word is said about how to assess the efficacy of a mentor.

This lacuna in the scholarship is surprising because some of the earliest research school studies (i.e. Geison, 1981; Morrell, 1972) identified one of the defining characteristics of successful research schools as having a "charismatic" director.[412] All historical scholarship indicates that the presence of such a charismatic director was a key factor in the success or failure of a given research school. There were, to be sure, other issues involved. For one thing, the presence or absence of institutional support – both financial and

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[411] Stephanie J. Bird, "Mentors, Advisors, and Supervisors: Their Role in Teaching Responsible Research Conduct," in *Mentoring and the Responsible Conduct of Research*, ed. Stephanie J. Bird and Robert L. Sprague, Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001), 455-468; Piper Fogg, Piper, "The Catalytic Mentor: An Award Winning Chemist at Rutgers University Takes Students under Her Wing" [The Faculty], *The Chronicle of Higher Education* 49, no. 47 (Aug 2003): A-10; http://oasis.oregonstate.edu/search/tThe+Chronicle+of+Higher+Education/tchronicle+of+higher+education/1%2C2%2C5%2CE/c8561056116&FF=tchronicle+of+higher+education&2%2C%2C4%2C1%2C0 (22 Jan 06); Frederic Lawrence Holmes, *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists* (New Haven, CN: Yale University Press, 2004); Robert Kanigel, *Apprentice to Genius: The Making of a Scientific Dynasty* (Baltimore, MD: Johns Hopkins University Press, 1986); Donald Kennedy, *Academic Duty* (Cambridge, MA: Harvard University Press, 1997); Association for Women in Science, *Mentoring Means Future Scientists: A Guide for Developing Mentoring Programs Based on the AWIS Mentoring Project*, 1993; Deborah C. Fort, ed., *A Hand Up: Women Mentoring Women in Science* (Washington DC: Association for Women in Science, 1995).

[412] Geison, "Scientific Change," 1981; Morrell, "The Chemist Breeders," 1972.

political – was a key determinant in the viability, durability, and historical significance of a research school. Even with institutional support however, it seems that without a suitable leader (i.e. a charismatic director), research schools tended to founder or never form at all.

Still, none of the scholarship has gone beyond labeling the ideal director as "charismatic" and suggesting that it was desirable for this individual to have a solid scientific reputation and influence within the field. To the extent that the director's interaction with students is discussed at all, the emphasis is typically on the tacit versus explicit transmission of artisanal competencies from master to apprentice. Usually, these studies make reference to the analyses of Ludwig Fleck and Michael Polanyi.[413] So, how does John Wheeler stack up as a 'charismatic director'? This question will require some unpacking.

In 1981, building on J. B. Morrell's 1972 article, "The Chemist Breeders: The Research Schools of Justus Liebig and Thomas Thomson," the historian of science Gerald L. Geison established the now (2009) standard definition of research schools: "[S]mall groups of mature scientists pursuing a reasonably

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[413] H. M. Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," *Science Studies* 4 (1974), 165-186; Harry Collins, *The Shape of Actions: What Humans and Machines Can Do* (Cambridge, MA: MIT Press, 1998); Ludwig Fleck, *Genesis and Development of a Scientific Fact*, trans. Fred Bradley and Thaddeus J. Trenn (Chicago: University of Chicago Press, 1970); Kathryn M. Olesko, "Tacit Knowledge and School Formation," in *Research Schools: Historical Reappraisals*, 16-29; Michael Polanyi, *Science, Faith, and Society* (Chicago: University of Chicago Press, 1964 [originally in 1945]); Michael Polanyi, *The Tacit Dimension* (New York: Doubleday, 1966).

coherent programme [sic] of research side-by-side with advanced students in the same institutional context and engaging in direct, continuous social and intellectual interaction."[414] Note here that by inclusion of the phrase, "in the same institutional context," Geison's definition of a research school is, at least inferentially, tied to a specific location.

Here, it is necessary to pause briefly and acknowledge the literature that articulates the distinction of research school from "research group." The scholarship of historian Joseph Fruton overlaps that of Geison in the study of Justus von Liebig and his students. In contrast to Geison's term 'research school' Fruton suggests that Liebig and others were actually a "research group." In Fruton's view, the term 'research group' preserves a focus on a single institution. He notes:

> I prefer the latter term [research group] because *research school* has also been applied to a community of scientists, not necessarily located at a single institution, or even in the same country, who are united solely by a common interest in a particular direction of research.[415]

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[414] Geison, "Scientific Change," 23; see also Geison, "Research Schools and New Directions in the Historiography of Science," 227-228; Morrell, "The Chemist Breeders, 1-46; Morrell, "W. H. Perkin, Jr., at Manchester and Oxford", 124-125.

[415] Joseph Fruton, *Contrasts in Scientific Style: Research Groups in the Chemical and Biochemical Sciences* (Philadelphia: American Philosophical Society, 1990), footnote on 1-2; See also, Joseph Fruton, "The Liebig Research Group: A Reappraisal," *Proceedings of the American Philosophical Society* 132 (1988): 1-66, 4: Here, Fruton appears to use the terms "research group" and "research school" interchangeably.

For further explication, Fruton refers his readers to the Russian scholar V. L. Gasilov.[416]

From the standpoint of the study of mentors, Fruton's point seems to be well taken. All things being equal, the institutional setting is irrelevant to the mentoring process. That said, there are consequences associated with institutional affiliation. If Wheeler had moved to another university that was among the elite graduate schools in physics, Fruton's definition of a research school ("a community of scientists, not necessarily located at a single institution") would be operative for our study. However, as we will see, there is and was a difference in the caliber of students who were admitted to Texas as opposed to those admitted to Princeton, and this circumstance appears to have consequences in the metrics I use to assess mentoring outcomes. Therefore, I have disaggregated the tabular data on Wheeler's mentoring outcomes into two tables that compare Wheelers mentoring outcomes with his colleagues at Princeton separately from those of his colleagues at Texas. To be clear, while I will employ the Geison's research school with its ties to location, ("in the same institutional context"), for our purposes, the operative aspect Gieson's model is its pedagogical imperative ("mature scientists ... side-by-side with advanced students"). With that stipulation in hand, the Geison-Morrell term 'research school,' as defined by Geison and Morrell

[416] Fruton cites V. L. Gasilov, *Voprosy Optimizatsii Nelineinykh Sistem Avtomaticheskogo Upravleniia* (Moscow: Biblioteka Akademii nauk SSSR, 1977).

(hereafter the Geison-Morrell model) is both adequate and apropos for the purposes of this dissertation.

In the Geison-Morrell model, there are fourteen separate qualities whose presence or absence determines the success of a given research school. These are: the presence of a charismatic leader; the presence of a leader with a research reputation; the presence of an informal setting and leadership style; the presence of a leader with institutional power; the presence of social cohesion, loyalty, and esprit de corps; the presence of a focused research program; the presence of simple and rapidly exploitable experimental techniques; the invasion into a new field of research; the presence of a pool of potential recruits; the presence of access to or control of publication outlets; the ability of students to publish early under their own names; the school's success in producing and placing a significant number of students; the institutionalization of the school in a university setting; the presence of adequate financial support.[417] In this section I will focus on John Wheeler's suitability for the designation of "charismatic leader."

One could certainly argue that in the 1938 – 1976 timeframe, the Princeton Physics Department was quite literally awash in 'charismatic directors.' As I have shown in the last chapter, even allowing for the high caliber of students that Princeton was able to attract, there was a great deal of mentoring proficiency in the Department of Physics. It may be recalled from

[417] Geison, "Scientific Change," (1981), 25.

Chapter One that the criterion of teaching effectiveness, particularly with graduate students, seemed to be a prominent factor in the 1938 hiring of John Wheeler. It is also worth note that in the 1938 – 1976 timeframe, there were only six chairs of the physics department at Princeton and four of them (H. D. Smyth, Chair of Physics 1937 – 1950; A. G. Shenstone, Chair of Physics 1950 – 1960; W. Bleakney, Chair of Physics 1960 – 1967; R. H. Dicke, Chair of Physics, 1967 – 1970) were Princeton Alumni.[418] It is therefore reasonable to presume that the hiring philosophy that placed a high priority on teaching effectiveness, particularly with graduate students, continued throughout John Wheeler's tenure at Princeton, and all things being equal, Princeton would hire professors who seemed to be promising mentors. Even so, Wheeler's Index of Student Impact (nearly 24% of former apprentices with "Renowned" publications and nearly 61% of former apprentices with "Very Well-Known" papers to their credit) suggests that even among the gifted mentors at Princeton, he stood out. But was Wheeler charismatic in the Geison-Morrell sense of the term?

[418] See Princeton University General Catalogues, 1937–1938 through 1977–1978, PRIN; see also Princeton University Graduate Alumni Index, 1839-1998, http://www.princeton.edu/~mudd/databases/graduate.html (02 Mar 2009) and Princeton University Undergraduate Alumni Index, 1921 - 1979, http://www.princeton.edu/~mudd/databases/alumni2.html (02 Mar 2009). The Princeton alumni who served as Physics Dept. Chairs were H. D. Smyth, Ph.D. 1918; A. G. Shenstone, Ph.D. 1923; W. Bleakney, Ph.D. 1932; R H. Dicke, A.B. 1939. Dicke earned his Ph.D from the University of Rochester; see also Princeton University Press Release, "Princeton Physicist Robert Dicke Dies," 04 Mar 1997, http://www.princeton.edu/pr/news/97/q1/0304dick.html (02 Mar 2009).

At the outset of his 1981 article, Geison pays homage to J. B. Morrell, who first raised the issue of charisma in a research school director. Indeed, Morrell is downright effusive on the subject:

> The creation, maintenance and growth of the school's loyalty, cohesion and confidence depended, too, on the director's charismatic powers, which at best reinforced his institutional power ... the term is useful if it conveys the idea of extraordinarily effective, indeed messianic, leadership. Such charisma which was most effectively exerted in informal pre-bureaucratic contexts, helped to draw students in sufficient numbers to make the school viable. It enforced the standards and styles of work adopted by the school. It exacted from the students an unflagging almost fanatical devotion to research, particularly at times of intellectual failure and disappointment, and on occasion it also imposed fervent specialization. It contributed strongly to the school's sense of its own novel and distinctive identity and importance. And it compelled unquestioning and unswerving loyalty to the master and his school. Though a research school existed primarily to advance knowledge, its atmosphere could be highly evangelical as the prophet broke through accepted conventions and led his devoted followers into unexplored and promising lands of enquiry ... Indeed the extent to which students wished to be known as the pupils of a certain director indicates the strength of his charisma.[419]

On one hand, Morrell's statement, insofar as it is applied to modern research schools, seems to overstate the case. There is no evidence that John Wheeler or any of his colleagues considered themselves "messianic." Nor is there any indication that they required an "unquestioning and unswerving loyalty." Indeed, as was shown in the preceding chapters, Wheeler tended to see

[419] Morrell, "Chemist Breeders" (1972), 6-7.

himself more as a collaborator than a mentor. Witness his oft repeated aphorism, “Universities have students to teach the professors.”[420]

On the other hand, it is clear from the recollections in *Family Gathering* that Wheeler’s students saw him as the ‘bearer of a new physics,’ and virtually without exception, they wanted to be known as part of the ‘Wheeler family.’ This topic deserves further explication.

Charisma, according to German sociologist Max Weber (1864 – 1920), takes a number of forms. Among these is a type of charisma that is specific to a given context, or in Weber's language, “qualitatively particularized.” This type of charisma seems somewhat less 'messianic' and more appropriate to the modern research school than the form of charisma described by Morrell. Weber elucidated this contextual charisma as follows:

> Charisma can be, and of course regularly is, qualitatively particularized. This is an internal rather than an external affair, and results in the qualitative barrier of the charisma holder’s mission and power. In meaning and in content the mission may be addressed to a group of men who are delimited locally, ethnically, socially, politically, occupationally, or in some other way. If the mission is thus addressed to a limited group of men, as is the rule, it finds its limits within their circle.

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[420] John Archibald Wheeler, “Wheeler, John Archibald, 1911 – ,” interview by Kenneth W. Ford (transcript) Princeton, NJ and Meadow Lakes, NJ, 06 Dec 1993 – 18 May 1995, American Institute of Physics. Oral History Inteviews [OH5]; the sentiment 'Universities have students to teach professors,' is expressed on 1209, 1906, and 2318. These particular interviews were conducted 14 Feb 1994 – 10 Jan 1995; See also John Archibald Wheeler and Kenneth Ford. *Geons, Black Holes, and Quantum Foam: A Life in Physics* (New York: W. W. Norton, 1998), 150.

Of course, Weber continues, charisma is impermanent at best and fleeting at worst:

> By its very nature, the existence of charismatic authority is specifically unstable. The holder may forego his charisma; he may feel ’forsaken by his God,’ as Jesus did on the cross; he may prove to his followers that ’virtue is gone out of him.’ ... The charismatic leader gains and maintains authority solely by proving his strength in life. If he wants to be a prophet, he must perform miracles; if he wants to be a war lord, he must perform heroic deeds. Above all, however, his divine mission must ’prove’ itself in that those who faithfully surrender to him must fare well. If they do not fare well, he is obviously not the master sent by the gods.[421]

Synthesizing these concepts, it appears that charismatic mentoring in science is evidenced by two criteria: a distinguished career and the production of successive generations of elite scientists. In Wheeler’s case, using Morrell’s and Weber’s language, Wheeler continued throughout his career to prove his own strength as a pace-setting theorist, performing heroic deeds as he opened up one field of physics after another. His example and his collaboration with students, often in informal pre- or non-bureaucratic contexts, enforced his own standards and styles of works on his students, as later attested by them. Those who surrendered to his mentorship fared well.

The sociologist Harriet Zuckerman makes this case in another context when she traces the intellectual lineage of Hans Krebs (1900 – 1981) through four generations of Nobel laureates and three generations of eminent chemists

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[421] Max Weber, *From Max Weber, Essays in Sociology,* trans and ed. H. H. Gerth and C. Wright Mills (London: Oxford University Press, 1946; reprint New York: Galaxy, 1965), 247, 248-249.

(including Justus von Liebig) all the way to Antoine-Laurent Lavoisier (1743 – 1794).[422] So, how does Wheeler stack up?

There is no question of John Wheeler's "research reputation." This is a point that has been established earlier in this study. Wheeler's accomplishments as a physicist are broad in scope and significant in impact. To recap a few highlights: Wheeler co-authored the first paper on the generalized mechanism of nuclear fission; he played a key role in the Manhattan Project (particularly the development of the reactors used for plutonium production); he made significant contributions to the field of quantum electrodynamics; he was an important member of the research team that developed the hydrogen bomb; and Wheeler and his students have made substantial progress in general relativity, especially in regard to astrophysics and cosmology.

Wheeler's personal publication record is, in itself, ample testimony to his scientific productivity as well as the significance of his work. As we see from his personal bibliography (Appendix B, page 343), Wheeler has three patents and 396 publications to his credit. The impact of this oeuvre is evident in the citation counts that emerge from a Google Scholar search. John Wheeler is credited with four 'Renowned' publications (i.e. 500 plus citations); six 'Famous' publications (i.e. 250-499 citations); and twelve 'Very Well-

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[422] Zuckerman, *Scientific Elite*, 150. For the full listing of Zuckerman's master-apprentice chain, see note [7], Introduction.

Known' publications (i.e. 100-249 citations).[423] Here it is also useful to recall that even with the mysterious redundancy issues in Google Scholar, 'Very

[423] See Google Scholar, find a: "JA Wheeler," http://scholar.google.com/scholar?as_q=&num=10&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JA+Wheeler%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= (02 Mar 09), The 'Renowned' publications include: Niels Bohr and John Archibald Wheeler, "The Mechanism of Nuclear Fission," *Physical Review* 56, No. 5 (01 Sep 1939), 426-450; David Lawrence Hill and John Archibald Wheeler, "Nuclear Constitution and the Interpretation of Fission Phenomena," *Physical Review* 89, No. 5 (01 Mar 1953), 1102-1145; Tullio Regge and John Archibald Wheeler, "Stability of a Schwarzschild Singularity," *Physical Review* 108, No. 4 (15 Nov 1957) 1063-1069; Charles W. Misner, Kip S. Thorne, John Archibald Wheeler, *Gravitation* (New York: W. H. Freeman, 1973). The 'Famous' publications include: Richard Phillips Feynman and John Archibald Wheeler, "Interaction with the Absorber as the Mechanism of Radiation," *Reviews of Modern Physics* 17, No. 2-3 (01 Apr 1945), 157-181; John Archibald Wheeler and Richard Phillips Feynman, "Classical Electrodynamics in Terms of Direct Interparticle Action," *Reviews of Modern Physics* 21, No. 3 (01 Jul 1949), 425-433; Dieter R. Brill and John A. Wheeler, "Interaction of Neutrinos and Gravitational Fields," *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957), 465-479; John Archibald Wheeler, *Geometrodynamics* (New York: Academic Press, 1962); Edwin F. Taylor and John Archibald Wheeler, *Spacetime Physics* (New York, W. H. Freeman, 1963); Ignazio Ciufolini and John Archibald Wheeler, *Gravitation and Inertia* (Princeton, NJ, Princeton University Press, 1995). The 'Very Well-Known' publications include: John Archibald Wheeler, "Molecular Viewpoints in Nuclear Structure," *Physical Review* 52, No. 11 (01 Dec 1937), 1083-1106; John Archibald Wheeler, "Polyelectrons," *Annals of the New York Academy of Sciences* 48, No. 3 (11 Oct 1946), 219-238; John Archibald Wheeler, "Geons," *Physical Review* 97, No. 2 (15 Jan 1955), 511-536; John A. Wheeler, "Assessment of Everett's "Relative State" Formulation of Quantum Theory," *Reviews of Modern Physics* 29, No. 3 (1 Jul 1957), 463-465; J. J. Griffin and J. A. Wheeler, "Collective Motions in Nuclei by the Method of Generator Coordinates," *Physical Review* 108, No. 2 (15 Oct 1957), 311-327; J. A. Wheeler, "On the Nature of Quantum Geometrodynamics," *Annals of Physics* 7, No, 6 (Dec 1957), 604-614; Kenneth W. Ford and John A. Wheeler, "Classical Electrodynamics in Terms of Direct Interparticle Action," *Annals of Physics* 7, No. 3 (Jul 1959), 259-286; R. F. Baierlein, D. H. Sharp, and J. A. Wheeler, " Three Dimensional Geometry as Carrier of Information about Time," *Physical Review* 126, No. 5

Well-Known' publications rank in the ninetieth percentile of citation count (and therefore in significance) of all published research in physics. In view of the foregoing, it is not surprising that, even in the absence of a Nobel Prize, the sociologist Harriet Zuckerman places Wheeler among the "ultra-elite" of physicists.[424]

The fate of Wheeler's students, or what is called scientific reproduction (i.e. the production of successive generations of scientists), has been addressed at length earlier in this dissertation. Suffice it to say that quite an number of Wheeler's former apprentices (e.g. Nobel Laureate Richard Feynman, Dieter Brill, John Toll, Ken Ford, Charles Misner, Kip Thorne, Jacob Bekenstein, to name but a few) have gone on to distinguished careers. What is significant is how many of the contributors to *Family Gathering* discuss Wheeler's continuing influence on them, and through them, to their own

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(01 Jun 1961), 1864-1865; Remo Ruffini and John Archibald Wheeler, "Introducing the Black Hole," *Physics Today*, 24, No. 1 (Jan 1971), 30-36, 39, 41; John Archibald Wheeler, "Superspace and the Nature of Quantum Geometrodynamics," in *Quantum Cosmology*, ed L. Z. Fang and R. Ruffini (Teaneck, NJ, World Scientific Publishing, 1987), 27-92; John Archibald Wheeler, " Information, Physics, Quantum: The Search for Links," in *Complexity, Entropy, and the Physics of Information, Proceedings of the Santa Fe Institute Workshop* 29 May - 10 Jun 1989, Santa Fe, NM, ed. Wojciech H. Zurek (Santa Fe, Westview Press, 1990), 3-28.

[424] Zuckerman, *Scientific Elite,*104; See also, Kip S. Thorne, and Wojciech H. Zurek, "John Archibald Wheeler: A Few Highlights of His Contributions to Physics," in *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler,* ed. Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller (Princeton, NJ: Princeton University Press. 1988): 3-13; John R. Klauder, "An Introduction," *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday,* ed. John R. Klauder (San Francisco: W. H. Freeman and Co., 1972), 10-11.

students. The letter of John S. Toll is particularly striking. Toll, who is now (2009) President Emeritus of Washington College and Chancellor Emeritus of the University of Maryland, also served as Professor and Chair of the Department of Physics and Astronomy at the University of Maryland from 1953 to 1965. At the time of his *Family Gathering* letter to Wheeler (23 June 1977), Toll was president of SUNY at Stony Brook and making preparations to serve as president of the University of Maryland. In that letter, Toll described his own students as Wheeler's 'grandchildren' and their students as Wheeler's great-grandchildren. Moreover, since a number of Wheeler's students were among the faculty of the department of physics and astronomy at Maryland, Toll observed that Wheeler had, in effect, inspired the whole department. Toll even spoke of building SUNY in the “Wheeler spirit.” Regarding Wheeler's charisma as a mentor, Toll wrote:

> I remember your [Wheeler] speaking of the “charismatic chain” that was so essential to good scientific work—a sequence of apprenticeships in which the spirit of research was passed from one person to another. Certainly you have been a uniquely effective source of such a large charismatic chain.[425]

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[425] *Family Gathering,* John S. Toll, 66-72; For John Toll's career see, University of Maryland, “John Sampson Toll, Curriculum Vitae,” available online: http://www.physics.umd.edu/people/faculty/cv/TollCV.pdf (21 Aug 2005) and Washington College, “Meet the Administration: John S. Toll,” available online: http://faculty.washcoll.edu/admin_bios/toll.html (26 May 2006). See also *Family Gathering*, 34, 103, 125, 164, 429: In addition to Toll, the former Wheeler students at Maryland included Gilbert Plass, James J. Griffin, Dieter Brill, and Charles Misner. Also, at the time of Toll's letter, Bahram Mashoon had just completed a two year post-doc at Maryland.

Clearly, in the eyes of John Toll and others, Wheeler was very successful as a charismatic progenitor of ‘successive generations of scientists. In light of the foregoing, and employing Max Weber's definition of particularized charisma, I adduce that John Wheeler satisfied the charismatic leader criterion that Geison and Morrell have established for a successful research school. But can we conflate research school leadership with mentoring?

Conceivably, it could be argued that a mentor's primary concern is the advancement of his or her apprentices while a research school leader concentrates on the production of knowledge. Therefore, the argument continues, directing a research school is a separate enterprise from mentoring. On the other hand, in order to survive, research schools are compelled to instruct their apprentices in the craft of doing science, including multiple ways to think about the science they are doing, as well as the professional standards of quality and production that will be expected of them once they have completed their apprenticeship.

The person responsible for this instruction, in the Geison-Morrell ideal research school, is a ‘charismatic’ director. That said, just as all scientists are not equally capable, so too all mentors are not equally skillful. Indeed, one reason for choosing John Wheeler as the subject for this dissertation was his perceived effectiveness in the role of mentor. Moreover, the production of knowledge and the professional socialization of scientific apprentices are not

mutually exclusive propositions. As Frederic L. Holmes, J. B. Morrell, and others have pointed out, even though Justus von Liebig moved away from the frontiers of organic chemistry to 'agricultural chemistry', he still continued to produce chemical knowledge *and* knowledgeable chemists at a prodigious rate.[426] The case of John Wheeler, as detailed above, serves to reinforce the argument that the production of large amounts of knowledge and the professional socialization of large numbers of scientists are not mutually exclusive.

Of course, having a charismatic leader with a solid research reputation are only two requirements of the Geison-Morrell model. In the next section, I will address the question of how Wheeler and his students fit with the other criteria of the ideal research school.

Section 5.3 John Wheeler as a Geison-Morrell Exemplar

In his 1981 *History of Science* article, Gerald Geison developed a chart, which incorporated the features of J. B. Morrell's ideal research school and enabled a side-by-side comparison of various research schools with respect to the fourteen salient indicators of a given research school's long-term success.[427] In the preceding section, I have addressed and confirmed

[426] Fruton, “The Liebig Research Group: A Reappraisal,” 2-5; Fruton, *Contrasts in Style,* 16-19; Holmes, F. L. “Justus von Liebig,” in *Dictionary of Scientific Biography,* ed. Charles Coulston Gillispie (New York: Scribner and Sons, 1973), 344-347;

[427] Geison, “Scientific Change” (1981), 24.

Wheeler’s status as a charismatic leader with a solid reputation for research, thus satisfying the first two of the fourteen Geison-Morrell criteria. This section addresses Wheeler’s congruence with the remaining twelve.

Among the eight schools chosen for Geison's comparison were three research schools that had shown sustained success (Justus von Liebig's school of Chemistry at the University of Giessen, Michael Foster's school of physiology at the University of Cambridge, and Arthur A. Noyes' school of physical chemistry at Caltech); two schools that had achieved temporary success (Pierre-Simon Laplace and Claude Louis Berthollet’s “Arcueil School” of physics and chemistry (c. 1800-1813) and Enrico Fermi's school of nuclear physics at the University of Rome); and four schools that were partial or relative failures (Thomas Thomson's school of chemistry at the University of Glasgow, John Scott Burdon-Sanderson's schools of physiology at University College London and Oxford University, Ira Remsen's school of chemistry at John's Hopkins University, and Wilder D. Bancroft's school of physical chemistry at Cornell University).[428]

From Geison's original selections, I have chosen to compare Wheeler to a school which had sustained success (Justus von Liebig in Giessen), a school which had temporary success (Enrico Fermi in Rome), and a school which was a partial or relative failure (Ira Remsen at Johns Hopkins). This tabular comparison of Wheeler's work as a mentor with other research schools

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[428] Geison, “Scientific Change” (1981), 22.

illustrates the importance of a proficient mentor to the institution *and* the individuals they serve.

The Geison-Morrell ideal research school model calls for an “informal setting and leadership style.” Here again, this aspect of Wheeler's mentoring has been addressed above. To what has been said earlier, we can add a report from *Family Gathering.* In his undated letter, Fred K. Manasse recalled numerous Saturday “group advising” sessions:

> The best general description of it I would now call a combination of apprenticeship with small group instruction. It was not a seminar, nor a lecture, nor the classical one-on-one advising. However, elements of each of these were present ... Although Johnny always made specific appointments, and for a precise time, our discussions were rarely just for the two of us. As a matter of fact, he deliberately arranged for several of us to be scheduled within 30-45 minutes of each other and thus there were almost always 4 or 5 people there at any one time. We sat around in his combination library-office in Palmer Hall discussing each other’s problems, obtaining references from his shelves, getting advice from each other and from John and generally discussing physics, relativity, research approaches etc. Whatever he did as catalyst to each of us apparently worked, because we all got our unique thesis ideas and eventually our PhD’s without really seeing Johnny alone more than half a dozen times during our three or four years at Princeton. I can still remember that familiar “Come In” at the appointed time, and in each instance being greeted by a different assortment of student colleagues all eagerly waiting to discuss their own problem while critiquing the current holder of the ear and/or chair nearest the “great man”. Perhaps this is the true and modern version of the Socratic system.

Manasse's report resonates with the recollections of former Princeton student and post-doctoral fellow, Paul Boynton. [429] Of course, the recollections of Manasse and Boynton bring to mind others' recollections of discussion groups at Bohr's institute in Copenhagen, with students competing for the ear (and approval) of Bohr.[430] That competition 'for the master's ear' however, was not part of the equation with Wheeler's Saturday seminars. As we saw in Chapter Three, Kip Thorne and Paul Boynton both recall that Wheeler's discussions featured a cooperative spirit and an unspoken code of conduct that sharply discouraged treading on the self-esteem of others.[431] In sum, Wheeler, as a mentor, has satisfied the Geison-Morrell criterion for an informal setting and leadership style.

The Geison-Morrell ideal model also calls for a "leader with institutional power." For our purposes, institutional power should be broadly defined. For example, John Wheeler never served as chair of the Department of Physics at Princeton, but he was hardly without institutional power. Although I suspect that he served on various departmental committees (i.e. admissions, hiring, promotion and tenure, etc.), I have found no archival evidence of such service. Wheeler did however, serve on a number of college wide committees including the Committee on Course of Study (1958 – 1959), the Advisory Committee on

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[429] *Family Gathering,* Fred K. Manasse, 258-259; Paul Boynton, personal communication with author, 07 Mar 2008, used by permission.
[430] David C. Cassidy, *Uncertainty: The Life and Science of Werner Heisenberg* (New York: Freeman, 1993), 184-185.
[431] *Family Gathering,* Kip Thorne, 306-307.

Policy (1962 – 1963), and perhaps most significantly on the Committee on Scientific Research and Higgins Fund (1970 – 1976), which set departmental research priorities.[432] But that is only part of the story.

Beyond the Princeton campus, John Wheeler wielded considerable influence in physics community. He served as president of the American Physical Society in 1966 and in 1967 he chaired the American Institute of Physics Committee on Physics and Society (COMPAS). [433] Additionally, Wheeler served as an advisor to several corporations (e.g. Dupont, Battelle, and Convair) and numerous government agencies (e.g. the General Scientific Advisory Board of the U.S. Air Force, the Advisory Committee of the Oak Ridge National Laboratory, and the General Advisory Committee on Arms Control and Disarmament). Wheeler mitigated a recruiting problem for the H-Bomb project when he succeeding in creating Project Matterhorn (which involved two areas of thermo-nuclear research—weapons development and fusion reactor development) at Princeton's Institute for Advanced Study. He created Project Jason as another avenue of recruitment to bring members of

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[432] This suspicion is based on a passage from page 216 of *Geons,* in which Wheeler recalls that, “I was largely responsible for bringing Bohm to Princeton …. I had visited Berkeley and, at my department’s request, interviewed Bohm. Upon my favorable recommendation, Princeton offered him a temporary appointment, and he joined the department in 1947.” ; see also, Faculty File, “John Archibald Wheeler,” PRIN-JAW; “Wheeler, John Archibald,” Box 12, Folder 12, PRIN-PHY; Princeton University General Catalogues 1938 – 1978.
[433] American Physical Society, "Officers of the Society, President," http://www.aps.org/about/governance/upload/Historical%20Officers-2.pdf (06 Mar 2009); “John Archibald Wheeler Archives, Princeton Files,” Series B. W564, Boxes 2 – 3, “American Physical Society,” APS-JAW.

the scientific community into defense related projects on a temporary basis without these scientists having to forego their academic research. Wheeler also came very close to establishing a national security laboratory at Princeton.[434] Thus, it appears that Wheeler had considerable influence in the narrow sense of the individual institutions (i.e. Princeton and Texas), but also and perhaps more importantly, in the broader sense of the physics community. Clearly John Wheeler met the Geison-Morrell requirement for institutional power.

The Geison-Morrell model for a research school also lists the criterion of, "social cohesion, loyalty, and esprit de corps or discipleship." This condition seems readily apparent in the case of Wheeler as a mentor. The title *Family Gathering* certainly suggests social cohesion, loyalty, and esprit de corps. Then too, both John Toll and Kip Thorne have (as noted above) commented

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[434] Wheeler interview with Ken Ford (14 Feb 1994 – 08 Nov 1994); For Wheeler's advisory committee work see 1201, 1407-1408, 1607-1608, 1705, 2003-2004, 2323; For Project Matterhorn see esp. 1407-1410; For Project Jason and the proposed national laboratory at Princeton see John Archibald Wheeler, "Wheeler, John Archibald 1911 –," interview by Finn Aaserud, [transcript] Princeton, NJ, (04 May and 28 November 1988), American Institute of Physics, Oral History Interviews [OH30194], n.p. and Finn Aaserud, "Sputnik and the 'Princeton Three:' The National Security Laboratory that was not Meant to Be," *Historical Studies in the Physical and Biological Sciences* 25 no. 2 (1995): 185-240, esp. 236-239; See also David Kaiser, "Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II," *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002): 131-160, 138; Bringing physicists into defense related work was seen by many as a matter of national urgency. Kaiser cites Princeton physics department chair Henry DeWolf Smyth who characterized scientific manpower as a "war commodity," a "tool of war," and a "major war asset," which therefore should be "stockpiled" and "rationed."

favorably on the "Wheeler spirit" that they hoped to infuse in their students and/or institutions. In addition to *Family Gathering,* four other Wheeler festschrifts have been compiled and published.[435] In each case these volumes consist almost entirely of essays by former Wheeler students, with occasional instances where two of Wheeler's former apprentices collaborated on a chapter. Finally, an overview of the bibliographies of former Wheeler students reveals several instances in which Wheeler 'family members' of various and separate academic generations collaborated with each other. Most notable of these is the now (2009) canonical opus *Gravitation* by Charles Misner, Kip Thorne, and John Wheeler.[436] In light of the foregoing, it seems clear that Wheeler, as a mentor, fulfills the Geison-Morrell condition of social cohesion and esprit de corps.

The Geison-Morrell model also calls for a "focused research program." Wheeler, as a mentor, has met this criterion—at least twice. In *Geons,* John Wheeler talks about three stages of his professional life; "Everything is Particles," "Everything is Fields," and "Everything is Information." Only two of these stages ("Everything is Particles" and "Everything is Fields") correspond to Wheeler's years at Princeton. In the 'Everything is Particles' stage Wheeler

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[435] A complete documentation of the Festschrifts can be found in note [44], Chapter 1.

[436] See *Gravitation* (San Francisco: W. H. Freeman and Co., 1973); This 1279 page opus, like the *Feynman Lectures*, remains in print, readily available, and continues to be a staple of physicists' libraries; This is a 'multi-generational' effort in that Thorne earned his Ph.D. from Princeton in 1965; Misner earned his Ph.D. from Princeton in 1957.

believed that, “all basic entities - neutrons, protons, mesons, and so on – [could be constructed] out of the lightest, most fundamental particles – electrons and photons.” While he was at Hanford, Wheeler continued, “I submitted a paper on this subject. It won a prize and appeared later, in 1946, in *Proceedings* of the New York Academy under the title 'Polyelectrons.' “[437] Indeed, particle work dominated Wheeler's career until the early 1950's. In addition to polyelectrons, other products of this particle fixation include Wheeler's well known Scattering Matrix and his QED work with Feynman.[438]

In 1952, Wheeler “fell in love with relativity” and came to see “a world made of fields, one in which the apparent particles are really manifestations of electric and magnetic fields, gravitational fields, and spacetime itself.” Later Wheeler observed that this attraction was more than a matter of aesthetic appreciation:

> What I learned in teaching the course was that the riches of Einstein's theory had been far from fully mined. Hidden beneath the equations, simple in appearance, complex in application-was a lode waiting to be brought to the surface and exploited.[439]

Stated alternatively, Einstein's theory of general relativity offered Wheeler and his students a good deal of 'low-hanging [conceptual] fruit' that he and they

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[437] Wheeler with Ford, *Geons,* 63; Jacob Bekenstein, in 16 Sep 05 letter to the author reports that in 1981 Bell Labs produced a polyelectron atom. In 1988, Cheuk-Yin Wong (another former Wheeler student) submitted a paper to Oak Ridge, *Proceedings* suggesting that polyelectrons are a source of anomalous positron peaks in heavy ion reactions.

[438] Wheeler with Ford, *Geons,* 63.

[439] Wheeler with Ford, *Geons,* 63, 231.

could harvest for quite some time. Here again, with his sequential concentrations on particle physics and relativity, Wheeler (as a mentor) has satisfies a Geison-Morrell condition for a successful research school.

The Geison-Morrell model further requires “simple and rapidly exploitable experimental techniques.” At first glance, this criterion would not seem to apply to a theoretical school. On the other hand, theoretical breakthroughs often yield rapidly exploitable ancillary problems. Jacob Bekenstein recalls that Wheeler would seize on the really significant ideas and exploit their publication value while the topic was fresh.[440] Bekenstein, in fact, encourages his own students to quickly build on important discoveries. David Goodstein, Vice-Provost at Caltech, has also suggested that “most people, if they have two real contributions to make, will carve them up and publish a number of Letters, etc. in addition to the two main papers.”[441] Indeed, as David Kaiser has pointed out, the Feynman diagrams were rapidly diffused and exploited, albeit along generational lines, and played a prominent role for decades in the pedagogy of physics.[442] Similarly, as we can see from the narratives and curricula vitae in *Family Gathering,* as well as in Wheeler’s own bibliography (Appendix B, p. 343), Wheeler has championed or collaborated on a number of theoretical breakthroughs that were exploited for bursts of

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[440] Jacob Bekenstein, email to the author, 16 Sep 2006.
[441] David Goodstein, email to the author 17 March 2006.
[442] David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005).

publication. It is clear, then, that the seventh Geison-Morrell criterion for Research School success applies to Wheeler and his students.

Another condition that the Geison-Morrell model specifies for a successful research school is the “invasion of a new field of research.” In the case of Wheeler, as a mentor, this is less obvious in the particle work than it is in relativity. It is however, clear that Wheeler and his students made some important innovations in particle work (e.g. quantum electrodynamics and the collective nucleus model).[443] Still the real 'invasion' was Wheeler's decision to pursue general relativity and to explore its relationships to cosmology and astronomy. Of John Wheeler's twenty-five most cited publications, seventeen originated in his 'Everything is Fields' period, while only eight stem from his 'Everything is Particles.' timeframe.[444] Granted, one could argue that since Wheeler's field physics was more recent, it was likely to attract more attention. Still, a quantitative overview of the early work on general relativity shows that the Wheeler academic family (the term 'academic family' goes beyond

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443 See Stanford University, Stanford Linear Accelerator Center. SPIRES High-Energy Physics Literature Database Available online: <http://www-spires.slac.stanford.edu/spires/hep/> (21 Aug 2005); Search terms: find “a Wheeler, J. A.” and “find a Hill, D. L. ; Wheeler's paper with Richard Feynman (“Interaction with the Absorber as the Mechanism of Radiation,” *Reviews of Modern Physics* 17 (1945): 157-181) has been cited more than 130 times; Wheeler's paper with David L. Hill (“Nuclear Constitution and the Interpretation of Fission Phenomena,” *Physical Review* 89 (1953): 1102-1145) has also been cited more than 130 times;

444 See Google Scholar; Search term: “find a Wheeler, J. A.,” available online: <http://scholar.google.com/scholar?num=100&hl=en&lr=&safe=off&q=author%3A%22J+A+Wheeler%22&btnG=Search> (20 Feb 06).

Wheeler’s students to include Wheeler's students' students, and post-docs who studied with Wheeler) was responsible for a significant percentage of the most influential publications.[445] While I am hesitant to employ the term “invasion,” it seems clear that Wheeler, as a mentor, had a notable impact in the sudden expansion of general relativity work. Consequently, Wheeler, as a mentor, satisfies the Geison-Morrell ‘invasion of a new field of research’ condition for a successful research school.

The Geison-Morrell model of an ideal research school includes the requirement for a “pool of potential recruits.” This criterion has obviously been met. Wheeler's reputation as a researcher has been well documented above. Moreover, since the days of Joseph Henry, Princeton's Department of Physics has remained among the United States' elite physics departments, and at no time before, during, or after Wheeler’s tenure has Princeton suffered a lack of graduate students in physics. Plainly, the Geison-Morrell condition for an available pool of recruits is satisfied.

The ideal Geison-Morrell research school also features “access to, or control of, publication outlets” as a condition for a successful research school. Here too, is a circumstance that is readily demonstrable. Wheeler himself authored some 215 publications during his Princeton years (1938 – 1977), and

[445] See Stanford University, Stanford Linear Accelerator Center, SPIRES High-Energy Physics Literature Database (28 May 2006); Between 1952 and 1972 some sixteen publications that included the keyword search phrase “general relativity” were cited 50 or more times; Wheeler family members were the authors of five of ten most cited publications returned by this search criteria.

fifty-four of these were co-authored by at least one Wheeler student, former student, or post-doc. In 1957 alone, Wheeler published ten papers, and seven of these were with students, former students, or post-docs. In fact, Wheeler and his students were the recipients of what Wheeler characterized as, “some good natured finger pointing” by colleagues who suggested that he and his students were attempting to 'take over' *Reviews of Modern Physics* by publishing eight papers in the July 1957 issue.[446] This circumstance indicates how Wheeler often found a way to get articles into print—sometimes without the enthusiastic support of journal editors. In 1952, for example, Wheeler (with David Hill) struggled to complete an important paper that was originally slated to be published in the *Annual Review of Nuclear Science.* Unfortunately, the paper turned out to be too long and was submitted too late for publication. Despite the paper's length and the inclusion of numerous illustrations, Samuel Goudsmit, editor of *Physical Review,* accepted it for publication and the paper appeared in 1953.[447] Six years later however (1959), Goudsmit was the recalcitrant editor. Wheeler reports:

> Ken [Ford] and I turned out three papers on semi-classical scattering. For one of them, we brought in two other colleagues

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[446] See “Bibliography of John Archibald Wheeler;” a draft form of this unpublished document has been made available to the author by Kenneth W. Ford. See also Wheeler with Ford, *Geons,* 266-267.

[447] Wheeler interview with Ken Ford (14 Feb 1994), 1208; Wheeler and Ford, *Geons,* 224; The paper referenced is: David Lawrence Hill and John Archibald Wheeler, “Nuclear Constitution and the Interpretation of Fission Phenomena,” *Physical Review* 89, (1953): 1102-1145; as of 31 January 2006, this paper had been cited 510 times.

> to help. One was David Hill, who had completed his Ph.D. work with me a decade earlier on the mechanics of nuclear fission. The other was Masami Wakano, then my graduate student, later my colleague and coauthor on numerous papers. When I submitted our three papers to *Physical Review* for publication, I got a cool reception—not for the first time—from that journal's editor, Sam Goudsmit ... Goudsmit didn't like wordiness and he didn't like pedagogy. I probably published less in *Physical Review* than most American physicists did, because I liked to be discursive and I liked to teach. Many of my papers appeared in another journal of the American Physical Society, *Reviews of Modem Physics*. The papers on semi-classical scattering Goudsmit found to be both too long and too pedagogical. Instead of abbreviating them, as he suggested, I submitted them to *Annals of Physics*, whose editor, Phil Morse, had been receptive in the past. There they appeared, unedited, in 1959.[448]

It appears that Wheeler's predilection for teaching theoretical physics carried over into his peer-reviewed publications. More to the point, it also appears that Wheeler, as a mentor, meets the Geison-Morrell requirement for ready access to publication outlets.

Another criterion for a successful research school is for the students to publish early and under their own names. This certainly seems to have been the case with Wheeler's apprentices. As already noted, among the contributors to *Family Gathering*, Dieter Brill, Fred K. Manasse, and Kip Thorne all commented that Wheeler was quick to share credit for joint work. Thorne also remarked that he conscientiously tried to emulate and pass on the "Wheeler code of ethics" to his students. Among other stipulations, the 'Wheeler ethic' demanded that, "When working jointly with a student, put your name on the paper only if your contribution was very great; put the student's

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[448] Wheeler and Ford, *Geons,* 291.

on even if his was small." In his *Family Gathering* letter of 27 August 1976, James York acknowledged Wheeler's assistance in promoting his [York's] work:

> I have you to thank for the guidance, encouragement, and opportunity that I needed in that crucial phase of my efforts in research. Moreover, you went a step further, as you have always done for your students and colleagues, in making the work known to others through your writings, talks, letters, and seminars. Your efforts in this direction were instrumental in helping me obtain my present position at the University of North Carolina, where John Wheeler is especially admired and respected![449]

Here, I should also note that Wheeler typically preferred to list the authors alphabetically so that on virtually every occasion where Wheeler published jointly with a student or post-doc, his [Wheeler's] name appeared last.[450] This evidence, coupled with the joint authorship data above, seems to indicate that Wheeler's students were able to publish early with their own names prominently featured in the publication.

The Geison-Morrell model of an ideal research school also requires the production and placement of a "significant number of students." John Wheeler has done very well by his students. Earlier in this dissertation, I have cited David Goodstein, Vice-Provost of Caltech, who has observed that, on average, a professor of physics at a research university will produce fifteen Ph.D.s over the course of his or her career. The context of Goodstein's article

[449] *Family Gathering,* Dieter Brill, 164; Fred K. Manasse, 258; Kip S. Thorne, 306; James W. York, 366.
[450] See Google Scholar; Search term: "find a Wheeler, J. A.," (20 Feb 06).

should be noted here. Goodstein was, in fact, lamenting the circumstance that U.S. graduate schools were producing too *many* physics Ph.D.s and as early as 1970, even prestigious institutions (e.g. Caltech) were having trouble placing their graduates. In contrast to Goodstein's lament, it appears that only one of the fifty-one individuals received their Ph.D. under the supervision of John Wheeler did not move on to a successful career in either academics, research, or industry. As detailed in his interview with Ken Ford, the memory of that failure clearly troubled Wheeler:

> Between that senior thesis and his Ph.D. in physics a dozen years later, Peter [Putnam] followed a circuitous route-and an even more convoluted route later. First, following his mother's wishes, he enrolled in the Yale Law School. His only brother had been killed in action in World War II, and his father had died soon after. His mother, Mildred, active in business in Cleveland, Ohio, was wealthy and strong-willed. But Peter's heart wasn't in the law. He dropped out of law school and took a part-time job with an electronics firm in New Hampshire, leaving time for him to read physics and philosophy. Through letters and visits, Peter kept in touch with me. Under the influence of Sir Arthur Eddington's *The Nature of the Physical World*, he had come to believe that all the laws of nature can be deduced by pure reasoning. Try as I might, I couldn't seem to disabuse him of this belief ...
>
> Finally, Peter followed my suggestion that he say good-bye to Eddington and get back to something timely and tractable in the world of physics. He enrolled as a graduate student in physics at Princeton, and asked to accompany me to Leiden. He audited my lectures and contributed some beautiful large drawings 'to illustrate ideas I was covering, but [Peter] didn't get seriously into research until he got back to Princeton. Then he finished a Ph.D. dissertation on the distribution of mass and energy in a star that is radiating at a prodigious rate ...
>
> During a postdoctoral teaching stint at Columbia University, Peter offered a physics course so full of philosophy that it

> attracted students from the nearby Union Theological Seminary. Before long, he obtained a teaching post at Union, where he was, as one fellow teacher there told me, the only person who could out-argue the great theologian Reinhold Niebuhr.
>
> Whatever mechanism in Peter's head propelled him through this world, it produced a jagged path. When, around 1971, his appointment at Union Theological Seminary was not renewed - largely, I suspect, for lack of publications -he decided to cast his lot with the civil rights movement and moved to Houma, a town in the bayou country of Louisiana, where he offered legal services to blacks for little or no fee. To provide simple food and rent on a tiny house that he shared with a companion, he worked as a night janitor in a church. When Janette and I, on our way to Texas in 1976, stopped to visit Peter, one look told us that he was truly impoverished. His mother visited more than once but was unsuccessful in getting him to leave Houma or to accept money. One night in 1987, cycling between his residence and his janitorial job, Peter was struck by a drunk driver and killed ... Peter was not one of my better students, and made no lasting contributions to physics. His talents did not flower in publications. He was perhaps a bit mad. Yet he deeply affected a few people, me among them. In our long correspondence over many years and in our occasional long conversations, he always had a way of raising questions and challenging accepted explanations that helped me sharpen my thinking about physics and about the way we humans describe and understand the world around us. [451]

At times, as I listened to the interview, Wheeler's regret seemed palpable:

> Thinking back on it now, I realize I didn't do my duty by Peter. I should have realized that he had this shortcoming of not getting things written up. His senior thesis at Princeton was so impenetrable that neither I nor anybody else in the department could make head or tail of it. I recommended the policy we finally followed: that is to give him a grade on it that was the average of his grades in his courses. But I would have done better if I had sat on him sentence by sentence.[452]

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[451] Wheeler and Ford, *Geons,* 254-256. Wheeler interview with Ford (04 Mar 1994) 1602; and later (24 Mar 1995-12 Apr 1995) 2406-2410.
[452] Wheeler interview with Ford (04 Mar 1994), 1602.

It is interesting to note that in Wheeler's interviews with Ken Ford and in the autobiography *Geons,* John Wheeler wrote (and spoke) about Peter Putnam at greater length and with more emotion than any other of his students. It is obvious from Wheeler's productivity as a physicist and from the discussion of Wheeler relationship with his mentors in Chapter 2, that physics was a passion in Wheeler's life. From the discussion above, it is equally clear that Wheeler had a passion for teaching. By accounts, Peter Putnam appears to the sole exception to Wheeler's success with placing his apprentices.

The Geison-Morrell model seems to emphasize the percentage of former students that have been placed. In my view however, this emphasis is misplaced on two counts. First of all the kinds of positions that Wheeler's former students have held, as well as the honors that they have earned, are more significant than the fact that they were merely placed. An adumbration of Wheeler's students' significant accomplishments follows: Richard Feynman won the Nobel prize in 1965; John S. Toll served as president of three academic institutions; Ken Ford served as Executive Director of the American Institute of Physics; Kip Thorne, Robert Wald, Jacob Bekenstein, and James York were all appointed to endowed professorships; Gilbert Plass, James Griffin, and Robert Wald have all served as chair of their physics departments; Brendan Godfrey became Director of the U.S. Air Force Office of Scientific Research; Clifford E. Rhoades Jr. served as Director of Mathematics and Space Science for U.S. Air Force Office of Scientific Research; Terrence

Sejnowski (who studied with Wheeler before switching to his research to biophysics) became Director of the Computational Neuroscience Laboratory at the Salk Institute.[453] There are, to be clear, other noteworthy accomplishments among Wheeler's apprentices. Space and time however, preclude a complete listing.[454]

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[453] In a 17 July 2009 email to the author, Sejnowski notes that he considered Wheeler to be a mentor even after he became John Hopfield's Ph.D. student at Princeton. As with Wheeler's relationship to Gregory Breit and Niels Bohr, Sejnowski believes himself fortunate to have had "two mentors, each unique in their approaches to science."; See also, Terrence J. Sejnowski, "Sources of Gravity Waves," *Physics Today* 27, No. 1 (Jan 1974), 40- 48.

[454] *Family Gathering,* Richard P. Feynman, 12; Gilbert N. Plass, 34; John S. Toll, 67; Kenneth W. Ford, 84; James J. Griffin, 103; Kip S. Thorne, 306; James W. York, Jr., 366; Brendan B. Godfrey, 391; Terrence Sejnowski, 420; Robert Wald, 422; Wheeler and Ford, *Geons,* 101 [Toll]; "Dr. Gilbert Plass" [Obituary],*The Bryan – College Station Eagle,* available online: <http://www.theeagle.com/region/records/obituaries/march2004/030304obits.php> (12 Sep 2005); John Sampson Toll, "John Sampson Toll, Curriculum Vitae," available online: http://www.physics.umd.edu/people/faculty/cv/TollCV.pdf (21 Aug 2005); Washington College. "Meet the Administration: John S. Toll," available online: <http://faculty.washcoll.edu/admin_bios/toll.html> (26 May 2006); Kenneth W. Ford, "Kenneth W. Ford -- Personal Web Page," available: <http://www.ianford.com/kenford/> (21 Aug 2005); James J. Griffin, "James J. Griffin Curriculum Vitae," available online: <http://www.physics.umd.edu/people/faculty/cv/GriffinCV.pdf> (21 Aug 2005); California Institute of Technology, "Kip S. Thorne, The Feynman Professor of Theoretical Physics" [Home Page], available online: <http://www.its.caltech.edu/~kip/> (26 May 2006); Cornell University, Department of Physics, "James W. York, Jr., Professor of Physics" [profpages], Available online: <http://www.physics.cornell.edu/profpages/York.htm> (25 May 2006); Air Force (U.S.), Office of Scientific Research. Biography: "Dr. Brendan B. Godfrey," available online: <http://www.afosr.af.mil/pages/godfrey.htm> (16 Sep 2005); Salk Institute, "Terrence J. Sejnowski," available online: <http://www.salk.edu/faculty/faculty/details.php?id=48> (21 Aug 2005); Robert

The most striking evidence however, is the publication data that this dissertation has brought to the fore. The two criteria that, according to the sociologist Harriet Zuckerman and others, set the scientific elite apart, are scientific productivity and a “scientific taste”, an aesthetic sense for significant problems that are coming ripe for solution.[455] The former attribute can be straightforwardly determined by publication data as found in Google Scholar; the latter attribute, as I have shown, can be inferred from the citation count for individual publications.

It seems clear that these measures of scientific productivity and the perceived significance of individual research publications authored by Wheeler’s former students, as opposed to the placement data emphasized in the Geison-Morrell model, is the most compelling indicator of mentoring proficiency. For example, a somewhat high percentage (31.4%) of John Wheeler’s fifty-one Ph.D. students (i.e. the combined total of his North Carolina, Princeton, and Texas years) exceeded the threshold for high scientific productivity. This compares to an average of 28.3% for Wheeler’s Princeton colleagues and 20.9% for his colleagues at Texas. The Index of

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M. Wald, “Robert M. Wald, Curriculum Vitae,” available online: <http://physics.uchicago.edu/t_rel.html#Wald> (21 Aug 2005).

[455] For productivity of the scientific elite see, Zuckerman, *Scientific Elite, 145*; Walter T. Scott, “Creativity in Chemistry,” in Rutherford Aris, H. Ted Davis, and Roger Stuewer, eds., *Springs of Scientific Creativity: Essays on Founders of Modern Science* (Minneapolis, MN: University of Minnesota Press, 1983), 285, 298; Fruton, *Contrasts in Scientific Style*, 23, 36, 38; Morrell, “The Chemist Breeders, 27, 30; For the inculcation of ‘scientific taste,’ see Zuckerman, 127–129.

Students' Impact is similarly indicative of proficiency. Wheeler's combined Index (i.e. the Index of Impact for all his Ph.D. advisees – North Carolina, Princeton and Texas) is 58.8%, with 23.5% of his former apprentices being credited with "Renowned" publications. The Index of Students' Impact for Wheeler's Princeton colleagues was 37.0% (12.3% having published "Renowned" works), and his colleagues in Texas had an Index of Students' Impact of 11.8% (with 2.7% having published "Renowned" works). Here again, I am compelled to note that less than 10% of all published research meets or exceeds our "Very Well-Known" threshold level of 100 citations.

As noted in Chapter Four, there is of course, an argument to be made that these percentages say more about the difference between Princeton and Texas, especially with regard to the caliber of graduate student who is granted admission to each, than they do about a distinction between Wheeler and his colleagues at either institution. In response, I point to the Student Productivity Index and note that in the individual cases of Princeton and Texas, the percentage of John Wheeler's former students who exceeded the threshold of high scientific productivity (i.e. the attribute that Zuckerman sees as most indicative of "elite" status), exceeds the average for his colleagues at each institution. There is an old Danish proverb that says (approximately): 'Anyone can do more with more … a craftsman can do more with less.'[456] Even

[456] I am indebted to my grandfather, the late Thorwald Christensen, for this and many other treasured insights.

allowing for a difference in caliber of students admitted to the respective institutions, John Wheeler appears to have done more with less.

In sum, Wheeler has produced and placed significant numbers of students. More to the point, the quantitative analysis of publication data suggests that Wheeler's students did good scientific work—and lots of it. Since Wheeler's mentoring took place within a university setting, it appears that Wheeler, as a mentor, has satisfied the thirteenth criterion for the Geison-Morrell model of a successful research school.

The fourteenth and final condition in the Geison-Morrell model of a successful research school is "adequate financial support." It is difficult to imagine a research setting in which additional funds could not be put to productive use. That said, Wheeler, through his extensive contacts in government and industry, seems to have kept his department and his students reasonably well-funded. The story of the Princeton cosmic ray laboratory is a useful example here. As World War II was winding down, high-energy particle physics became an important area of research. Wheeler, like many of his peers, believed that this area of research held great promise.[457] In June of 1945, Wheeler suggested three goals for physics research in the post-war era.[458] The goal nearest and dearest to his heart was cosmic ray investigation.

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[457] Wheeler interview with Ford (14 Feb 1994), 1206.
[458] J. A. Wheeler, "Three Proposals for the Promotion of Ultranucleonic Research #6: H. D. S.," 15 June 1945, copy to Smyth, in Physics Departmental Records, Chairman 1934-35, 1945-46, no. 1, Princeton

As the historian Peter Galison notes, given the evidence of protons being transformed into mesons in the upper atmosphere, Wheeler had a hunch that "that matter could be directly transformed into energy."[459] He contended:

> Discovery [of] how to release the untapped energy on a reasonable scale might completely alter our economy and the basis of our military security. For this reason we owe special attention to the branches of ultranucleonics—cosmic ray phenomena, meson physics, field theory, energy production in supernovae, and particle transformation physics—where a single development may produce such far-reaching changes.[460]

At first Wheeler believed that the research would be most expeditiously accomplished by having U.S. Air Force bombers carrying the experimental apparatus at an altitude of 40, 000 feet.[461] When that idea failed to gain traction, Wheeler, who believed that a high-energy particle accelerator was not in Princeton's immediate future, opted for a cosmic ray laboratory that would be located on or near the Princeton campus. He needed money and some allocated space, and the contacts that Wheeler had developed in government and industry were most helpful:

University Archives, cited by Peter Galison, "Physics Between War and Peace," in *Science, Technology, and the Military*. Vol. 12, part 1, of Sociology of the Sciences, ed. Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart (Boston: Kluwer Academic Publishers, 1988), 58.

[459] Galison, "Physics Between War and Peace," (1988), 58.

[460] J. A. Wheeler, "Three Proposals for the Promotion of Ultranucleonic Research #6: H. D. S.," 15 June 1945, copy to Smyth, in Physics Departmental Records, Chairman 1934-35, 1945-46, no. 1, Princeton University Archives, cited by Galison, "Physics Between War and Peace" (1988), 58.

[461] Galison, "Physics Between War and Peace" (1988), 58.

> Fortunately, an ancillary building at Princeton that Walker Bleakney had used for wartime shock-wave experiments was available. We established our cosmic-ray beachhead there. Most of the subsequent funding for the work of the laboratory came from the federal government. Some came also from the generous private contributions of many of my old Du Pont friends, including Crawford Greenewalt (who, as I noted before, became Du Pont's president), Dale Babcock, Lombard Squires, Charles Wende, Hood Worthington, H. C. ("Ace") Vernon, and George Graves. They established a fund named the Friends of Elementary Particle Research, from which I was able to allocate expenditures, especially to support students. By drawing on it sparingly to meet special needs when other funds were not available, I made it last many years.[462]

Thus, it appears that Wheeler and his cadre of apprentices satisfied the Geison-Morrell condition of adequate funding for a successful research school. Geison's 1981 essay also includes a chart developed by David Edge and Michael Mulkay.[463] The above documentation, which shows that the "Wheeler family" was in compliance with all but two of the Geison-Morrell criteria for a successful research school, is depicted on this chart.

In the section following Table 5.1, I correlate what has been learned of mentoring to the resonant themes in the emerging scholarship of scientific pedagogy.

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[462] Wheeler and Ford, *Geons,* 170; Wheeler interview with Ford (14 Feb 1994), 1206.

[463] David O. Edge and Michael Mulkay, *Astronomy Transformed: The Emergence of Radio Astronomy in Britain* (New York: Wiley, 1976), 382 . This chart, which has been replicated by Geison (p.25), details conditions that lead to the development of a scientific specialty.

Table 5.1 Comparison of Factors Affecting the Success of Research Schools[464]

School	Liebig	Wheeler	Fermi	Remsen
Charismatic Leader	yes	yes	yes	no
Leader with research reputation	yes	yes	yes	yes
Informal setting and leadership style	yes	yes	yes	no
Institutional power	yes	yes	yes	yes
Social Cohesion esprit de corps discipleship	yes	yes	yes	?
Focused research program	yes	yes	yes	yes
Simple and rapidly exploitable experimental techniques	yes	yes	yes	yes
Invasion of new field of research	yes	yes	yes	no

Legend: "yes" indicates that the feature appears to be present
"no" indicates that the feature appears to be absent
"?" indicates that the presence or absence in unclear

[464] Adapted from Geison, "Scientific Change" (1981), 24.

Table 5.1 Comparison of Factors Affecting the Success of Research Schools (cont.)

School	**Liebig**	**Wheeler**	**Fermi**	**Remsen**
Pool of potential recruits (graduate students)	Yes	yes	?	yes
Access to or control of publication outlets	Yes	yes	yes	yes
Students publish early and under own name	Yes	yes	?	?
Produced and placed significant numbers of students	Yes	yes	?	yes
Institutionalization in university setting	Yes	yes	?	yes
Adequate financial support	Yes	yes	yes	yes
Total number of “yes” answers	14	14	10	9

Legend: See above

Table 5.1 Comparison of Factors affecting the success or failure of a research school (adapted from Gerald L. Geison “Emerging Specialties and Research Schools”). Here, John Wheeler's 'school' is shown in comparison to a research school that Geison considers to be a sustained success (Justus von Liebig), a research school that Geison considers to have had temporary success (Enrico Fermi) and a research school that Geison considers to be a relative failure (Ira Remsen).

Section 5.4 Mentors as Instruments of Pedagogy

Over the past few years, David Kaiser, a historian of science at MIT, has produced a significant and promising body of scholarship that deals with the pedagogy of physics. Among other scholarship in this field is the work of Kathryn Olesko and Andrew Warwick.[465] By and large, this work is concerned with the training of physicists (i.e. didactic instruction as opposed to mentoring) and how elements of that pedagogy have emerged, developed, and become dispersed over time.

Just as I have noted a lacuna in the scholarship on research schools with regard to the role of mentors, Kaiser has noted that since the 1970s historians of physics have been fascinated with the interactions and relationships of established scientists to the exclusion of research on how the

[465] David Kaiser, "Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II," *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002), 131-160; David Kaiser, "Nuclear Democracy: Political Engagement, Pedagogical Reform, and Particle Physics in Postwar America," *Isis* 93, 2 (Jun 2002), 229-268; David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005); David Kaiser, ed. *Pedagogy and the Practice of Science* (Cambridge, MA.: MIT Press, 2005); David Kaiser, "Whose Mass is it Anyway? Particle Cosmology and the Objects of Theory," *Social Studies of Science* 36, No. 4 (Aug 2006), 533–564; David Kaiser, "Training Quantum Mechanics: Enrollments and Epistemology in Modern Physics," excerpted from *American Physics and the Cold War Bubble* (Chicago: University of Chicago Press, forthcoming); See also, Kathryn M. Olesko, *Physics as a Calling: Discipline and Practice in the Konigsberg Seminar for Physics* (Ithaca: Cornell University Press, 1991); Kathryn M. Olesko, "The Foundations of a Canon: Kohlrausch's Practical Physics," In *Pedagogy and the Practice of Science* ed. David Kaiser; and Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (Cambridge: Cambridge University Press, 2003).

education of these physicists guided those interactions within the scientific community.[466] To be clear, Kaiser is not disparaging this body of work. Rather his point is that there is more to the story. In particular, Kaiser notes that, "Scientists and engineers do more than pass down skills and knowledge to younger generations; they also strive to inculcate norms, roles, and personae."[467] In essence, Kaiser is describing a key aspect of mentoring, which is identical to the process that Harriet Zuckerman calls "professional socialization." [468]

The reader may recall from the introduction to this dissertation that Thomas Kuhn stressed the influence that the training of scientists had on the course of science. Because education in physics is textbook driven—indeed, problem driven—until the last year or two of Ph.D. work, scientists in training do not generally synthesize a world view that is cognizant of, let alone congruent with, the thinking of earlier scholars. Indeed, as Kuhn points out, the very training of scientists simultaneously instills a disregard for discarded hypotheses and a predilection to preserve and evaluate evidence in the light

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[466] Examples include, but are not limited to: Harry Collins, "The TEA set: Tacit Knowledge and Scientific Networks," *Social Studies of Science* 4 (1974), 165-186; Peter Galison, *How Experiments End* (University of Chicago Press, 1987); Peter Galison, *Image and Logic: A Material Culture of Microphysics* (University of Chicago Press, 1997)
[467] David Kaiser, "Introduction," in *Pedagogy and the Practice of Science,* ed. David Kaiser, 1–10, 6.
[468] Zuckerman, *Scientific Elite,* 123.

of the theoretical construct in which they have been trained. [469] Hence, Kaiser and others have chosen to examine certain elements and instruments of scientific pedagogy (e.g. textbooks, course syllabi, lecture notes, problem sets, Feynman diagrams) with specific focus on how these instruments have changed over time and thereby changed the manner in which physicists are trained.[470]

The point that Kaiser and others (e.g. Olesko and Warwick) are making is that the training of scientists has as much to do with the course of science as with the practices, interactions, and relationships of the nominal leaders of the scientific community. In the concluding chapter of Kaiser's edited volume, *Pedagogy and the Practice of Science*, Andrew Warwick and chapter co-author Kaiser observe, "It is also extremely important to recognize that scientific training, like science itself, has a history."[471] To overlook that history is to bypass a historical vein that is rich in insight.

Here is a parallel with my study of mentoring. As noted in Chapter 1, there is an formidable body of scholarship that deals with research schools as

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[469] Kuhn, *The Structure of Scientific Revolutions,* 167-169, 189; Thomas Kuhn, *The Essential Tension* (Chicago: University of Chicago Press, 1977), 305.
[470] David Kaiser, "A Ψ is Just a Ψ? Pedagogy, Practice, and the Reconstitution of General Relativity, 1942–1975," *Studies in History and Philosophy of Modern Physics* 29, No. 3 (Sep 1998), 321–338, 323; David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005)
[471] Andrew Warwick and David Kaiser. "Conclusion: Kuhn, Foucault,and the Power of Pedagogy," in *Pedagogy and the Practice of Science,* ed. David Kaiser, 393–410, 397.

well as an abundance of literature addressing the subjects of mentors and mentoring practice.[472] Despite the centrality of a ‘charismatic leader’ to the success of a research school however, the extant research school literature (with the exception of previous studies by this author) does not address the practices, especially the mentoring practices of a research school’s “charismatic leader.” Similarly, although a small subset of the mentoring literature involves the practice of mentoring in a scientific setting, the focus is almost entirely on the transfer of artisanal skills in laboratory and field-based science.

Although the study of pedagogy in science would seem to be a suitable avenue of research for historians of education, there appears to be little interest in the topic from that group of historical scholars. Warwick and Kaiser note that historians of education have heretofore largely concerned themselves with institutional history, or the history of educational reform, or the teaching of notable individuals such that, of the plethora of scholarship concerning the history of education, “virtually none of it is concerned with the relationship between training and the production of scientific knowledge.”[473] That circumstance, coupled with what Kaiser describes as the “fascination” that contemporary scholars have with historical interactions of established

[472] For an extensive sampling of Research School scholarship, see note [22] in Chapter One; for a sampling of mentoring scholarship see note [56] in Chapter One.
[473] Warwick and Kaiser, 393; Kaiser, “Introduction,” *Pedagogy and Practice,* 1.

scientists, means that the promising study of scientific pedagogy, much like the study of mentoring, has fallen between the cracks of contemporary scholarship.

And yet, promising insights have been developed in this dissertation (e.g. the quantitative analysis of mentoring proficiency) as well as the scholarship of Kaiser and his like-minded colleagues. In view of this circumstance, it seems clear that a synergetic overlap exists between the study of scientific pedagogy and the study of scientific mentoring such that, I contend here that mentors may profitably be considered as instruments of scientific pedagogy. Moreover, I contend that the study of mentoring in science establishes a bridge between the long established scholarship of research schools and the emerging literature of scientific pedagogy.[474]

Section 5.5 Conclusion

In this dissertation I have shown that scientific mentoring is a fruitful avenue of research that connects the well-established scholarship on the role of research schools in the development of science and the emerging scholarship regarding scientific pedagogy. I have also demonstrated that the proficiency of mentors can be objectively quantified through analysis of the

[474] I am pleased to report here that Professor Kaiser agrees with me on these two points and we have submitted application to the National Science Foundation with the aim of expanding this study with an eye towards its implications for the history of scientific pedagogy. Personal communication with author 12 Jan 08, 23 Jan 09.

work of their former apprentices with regard to scientific productivity and the significance of their published research as inferred from citation statistics. While these metrics enable an ‘apples to apples’ comparison, numbers alone do not tell the whole story, however. Analysis of the content of dissertation acknowledgements can often provide meaningful insight into the mentoring relationship.

So, what can or does a mentor pass along to his or her protégés? It has been well documented that mentors in laboratory and field settings pass along specialized and/or technical knowledge to their apprentices. Generally, there is some explicit instruction. In many cases however, the explicit didactic instruction is supplemented by the transfer of tacit knowledge. Laboratory techniques and observational practices are learned by imitation as much as instruction. Similarly, theoretical mentors pass the artisanal skills of calculation and conceptualization (i.e. formulating a problem so that it can be solved by standard and canonical means) on to their apprentices. But is that enough?

As Professor Kaiser has asserted, ‘Scientists are made, not born.” It seems that the environment that mentors provide their apprentices is at least as important as the skills and attitudes that they inculcate. The theme that runs throughout the acknowledgements of dissertations and theses is gratitude to that student’s mentor for providing the simultaneously nurturing and challenging environment that seemed to be catalytic to professional development.

Certainly this seemed to be the case of John Wheeler. The content analysis of dissertation and thesis acknowledgements completed under his supervision, coupled with the reminiscences in *Family Gathering*, as well as personal communications with his former apprentices, reveals a cyclical, almost timeless process. Over time, Wheeler's apprentices learned to look at problems in depth; they learned to think about physical phenomena from multiple frames of reference; they developed an ability to see the non-visible in physics with what Immanuel Kant called an Anschaulich vision (e.g. seeing the forces that shape a trajectory before a ball moves through space). That artisanal development was predicated on Wheeler's ability to recognize and nurture talent in his apprentices; just as Karl Herzfeld, Gregory Breit, and Niels Bohr recognized and nurtured Wheeler's talent. Beyond merely cultivating talent however, Herzfeld, Breit, and Bohr inculcated Wheeler with distinctive philosophies of physics and its place in the world, all of which shaped Wheeler as a physicist and a mentor.

It may also be useful here to recall another passage from Harriet Zuckerman's *Scientific Elite.* To set the stage, at this point in Zuckerman's narrative a physicist is reconstructing the key elements of what he (a presumption based on the context below) had gained from his mentor:

> I knew the techniques of research. I knew a lot of physics. I had the words, the libretto, but not quite the music. In other words, I had not been in contact with men who were deeply imbedded in the tradition of physics: men of high quality. This was my first

> real contact with first-rate creative minds at the high point of their power.[475]

The “music” that Zuckerman’s physicist learned from his mentor is identical to the Anschaulich vision that was transmitted though John Wheeler to his apprentices.

The maturation of Anschaulich vision is a familiar pattern to me. When I first went to sea, I had a “lubber’s eye.” That is to say that when I looked at water, I saw water—and only water. As I progressed in my profession however, I began to see more than water. Indeed, as a vessel Master, I could look at the water in an anchorage and discern the stage of the tide, the strength and direction of the tidal current, the strength and direction of the wind, the likelihood of precipitation within the previous twenty-four hours, and the relative efficiency of the local sewage treatment facility—a very different picture than I had perceived as a novice sailor.[476] That deeper vision—that anschaulich seeing of the non-visible—is part of what a skillful mentor will impart to his or her apprentices.

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[475] Zuckerman, *Scientific Elite,* 123.

[476] The term “Master” when employed in a maritime sense, is often misconstrued by the non-seafarer. Rather than connoting absolute power, it should be noted that one qualifies to serve as the “Master” of a vessel by virtue of demonstrating one’s *mastery* of the seventeen separate subject areas (i.e. subject areas ranging from ship construction and stability to celestial navigation) which pertain to the safe navigation and operation of a ship at sea. Thus, the term “Master,” which is short for ‘Master Mariner’ actually connotes a level of craftsmanship, similar to the technical craftsmanship that Wheeler and his colleagues inculcated in their apprentices.

Science is a creative process, and just as art historians gain insight by studying the training of an artist, so too historians of science can profit from tracing the professional development of scientists in a given discipline. We have seen that Wheeler's influence has been self-consciously transmitted by his former students on to their students. It seems likely and sensible that "Wheelerisms" and/or the "Wheeler spirit" will continue (with minor modifications) to be passed along to ensuing generations of physicists and cosmologists.

There is one aspect of this transmitted "Wheeler spirit" that resonates with my personal experience. Wheeler's enthusiasm—not just for physics, but for learning in general—is a common theme that runs throughout the narratives found in *Family Gathering*; the tape recordings (and transcripts) of interviews of former Wheeler apprentices, and the anecdotal memories that have been shared with me by those who knew and-or studied under John Wheeler. On Tuesday, 25 March 2008, shortly before he died (on Sunday, 13 April), I had the opportunity to meet with John Wheeler in his retirement home at Meadow Lakes, NJ.

In recent years, Wheeler had slipped into something of an Alzheimer's twilight. In addition to a somewhat transient lucidity, his hearing had diminished such that it was necessary to speak into a palm-sized amplifier in order to be heard. In all candor, I am sure the residents who sat around our meeting area were amused at the sight of a man accompanied by a Guide

Dog trying to communicate with a man who was all but deaf. Nonetheless, we had a very pleasant meeting. While my visual impairment prevented me from seeing his facial expressions, Ken Ford (former student and co-author of Wheeler's autobiography), who arranged the meeting, remarked immediately afterward that it had been one of John Wheeler's better days; he had smiled and nodded at appropriate times as I shared the plan and main points of my work. More to the point about enthusiasm, whenever I made an assertion, or disclosed a finding that he [Wheeler] thought was significant (e.g. 'mentoring as an underdeveloped area of scholarship'), he would tap my arm and give me a 'thumbs-up' signal— or even a fist pump—as he did when I mentioned the multiplicative impact of mentor. At one point, I made a joke about not being able to be a professional mariner because the Coast Guard took a *dim* view of captains who could not see buoys or read a navigation chart. At that moment however, I failed to speak directly into the amplifier and upon seeing others laugh, Wheeler immediately turned to Ken Ford and inquired, "What did he say?" When I repeated the punch line, John Wheeler tapped my arm and leaned back in his chair as if we were old friends sharing a good laugh. It is a poignant memory that I shall always treasure.

Returning to the here and now, my point is that, even in the final days of his life, John Wheeler's enthusiasm for learning and sharing new ideas was palpable.

This robust enthusiasm for learning—robust enough to buoy his apprentices when problems seemed insoluble or the completion of a research project seemed in doubt—is perhaps the most important quality that a scientific craftsman can inculcate in an apprentice, and the material from which chains of wisdom are forged.

Sources Consulted

Aaserud, Finn. “Sputnik and the ‘Princeton Three:’ The National Security Laboratory that was not Meant to Be.” *Historical Studies in the Physical and Biological Sciences* 25 no. 2 (1995): 185-240.

Abelson, Philip H. “Merle Anthony Tuve, June 27, 1901 – May 20, 1982.” http://www.nap.edu/html/biomems/mtuve.html (05 Feb 2009), n.p. Also in National Academy of Sciences, Biographical Memoirs. Vol. 70, 406-423. Washington, DC: National Academies Press, 1996.

Aczel, Amir D. *God’s Equation: Einstein, Relativity, and the Expanding Universe.* New York: Four Walls Eight Windows, 1999.

Adler, Carl G. and Byron L. Coulter. “Gallieo and the Tower of Pisa Experiment.” *American Journal of Physics* 46, no. 3 (Mar 1978): 199-201.

Air Force (U.S.), Office of Scientific Research. “Dr. Brendan B. Godfrey” [Biography]. http://www.afosr.af.mil/pages/godfrey.htm (16 Sep 2005)

Air Force (U.S.), Office of Scientific Research. “Dr. Clifford E. Rhoades” [Biography]. http://www.afosr.af.mil/pages/afrrhoa.htm (21 Aug 05).

Al Huang, Chungliang and Jerry Lynch. *Mentoring: The Tao of Giving and Receiving Wisdom*. San Francisco: HarperSanFrancisco, 1995.

American Institute of Physics. “Citizenship of Physics Ph.D.s,1966-2003” http://0www.aip.org.oasis.oregonstate.edu/statistics/trends/highlite/ed/figure6.htm (05 Jan 2006).

American Institute of Physics. “Focus and Coverage.” *Journal of Mathematical Physics* 47, no. 3 (Mar 2006) n.p. http://jmp.aip.org/jmp/ (22 Apr 2006)

American Institute of Physics. “Number of Physics Ph.D.s Conferred in the United States, 1900-2003”. http://0www.aip.org.oasis.oregonstate.edu/statistics/trends/highlite/ed/figure5.htm (05 Jan 2006).

American Philosophical Society – Membership in the APS. (n.d.). http://www.oldcity.dca.net/amphilsoc/default_test.cfm. (25 Oct 03)

American Physical Society – Prizes and Awards (n.d.) http://www.aps.org/praw/einstein/03winner2.html (25 Oct 03).

Ariew, Roger. "Pierre Duhem." *The Stanford Encyclopedia of Philosophy* (Winter 2008 Edition), edited by Edward N. Zalta. http://plato.stanford.edu/archives/win2008/entries/duhem/ (08 Feb 09). Stanford, CA: Stanford University, The Metaphysics Research Lab, Center for the Study of Language and Information.

Aris, Rutherford, H. Ted Davis, and Roger Stuewer, eds. *Springs of Scientific Creativity: Essays on Founders of Modern Science.* Minneapolis, MN: University of Minnesota Press, 1983.

Association for Women in Science. *Mentoring Means Future Scientists: A Guide for Developing Mentoring Programs Based on the AWIS Mentoring Project.* Washington, DC: Association for Women in Science, 1993.

Badash, Lawrence. *Scientists and the Development of Nuclear Weapons: From Fission to the Limited Test Ban Treaty, 1939-1963.* The Control of Nature. Amherst, NY: Humanities Press, 1998.

Barrow, John D., P. C. W. Davies, and Charles L. Harper, eds., *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity.* New York: Cambridge University Press, 2004.

Bernstein, Jeremy. *Quantum Profiles.* Princeton, NJ: Princeton University Press, 1991.

Bevilacqua, F. “The Emergence of Theoretical Physics in the Second Half of the Nineteenth Century.” In *Natural Sciences and Human Thought.* Edited by Robert Zwilling. New York: Springer-Verlag, 1995.

Ben-David, Joseph. *The Scientist’s Role in Society: A Comparative Study*. Englewood Cliffs, NJ: Prentice-Hall, 1971.

Bird, Stephanie J. “Mentors, Advisors, and Supervisors: Their Role in Teaching Responsible Research Conduct.” *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 455-468.

Birr, Kendall. “Industrial Research Laboratories.” In *The Sciences in the American Context: New Perspectives*, edited by Nathan Reingold. Washington, DC: Smithsonian Institution Press, 1979.

Bloch, Felix. “Biography” http://nobelprize.org/physics/laureates/1952/bloch-bio.html (24 Mar 06). Also in *Nobel Lectures, Physics 1942-1962.* Amsterdam: Elsevier Publishing Co., 1964.

Bohr, Aage. “Autobiography” http://nobelprize.org/physics/laureates/1975/bohr-autobio.html (24 Mar 2006). Also in *Lex Prix Nobel*. Edited by Wilhelm Odelberg. Stockholm: Nobel Foundation, 1976.

Boltzmann, Ludwig. “Model.” In *The Encyclopaedia Britanica*. 11th ed. Vol. 18. New York: Encyclopaedia Britannica, 1911: 638-640.

Bowditch, Nathaniel [original author]. *The American Practical Navigator* (1995 Edition). http://www.irbs.com/bowditch/ (16 Feb 2009).

Breit, Gregory. “The Distributed Capacity of Inductance Coils.” Ph.D. Dissertation, Johns Hopkins University, 1921.

Brock, William H. “Liebigania: Old and New Perspectives.” *History of Science* 19 (Sep 1981): 201-218.

Brock, William H. *Justus von Liebig: The Chemical Gatekeeper*. New York: Cambridge University Press, 1997.

Broome, Taft H. “Of Snow and Smith: Commentary on ‘Notes on a Pilgrimage to Science: A Fly on the Wall (David Smith)” *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 635-638.

Brown, W. Norman, comp. *John Hopkins Half-Century Directory: A Catalogue of the Trustees, Faculty, Holders of Honorary Degrees, and Students, Graduates and Non-graduates 1876-1926.* Baltimore, MD: The Johns Hopkins University Press, 1926.

Bush, Vannevar. *Science: The Endless Frontier: A Report to the President.* Washington, DC: U.S. Government Printing Office, 1945.

Bynum, W. F., E. J. Browne and Roy Porter, eds. *Dictionary of the History of Science.* Princeton, NJ: Princeton University Press, 1981.

Byrne, Peter. "The Many Worlds of Hugh Everett." Scientific American 297, no. 6 (Dec 2007): 98-105, Academic Search Premier, EBSCOhost, http://proxy.library.oregonstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=27431241&loginpage=Login.asp&site=ehost-live (23 Feb 2009).

California Institute of Technology. “Kip S. Thorne, The Feynman Professor of Theoretical Physics” [Home Page]. http://www.its.caltech.edu/~kip/ (26 May 2006).

Cassara, Ernest, ed. *Universalism in America: A Documentary History.* Boston: Beacon Press, 1971.

Cassidy, David C. *Uncertainty: The Life and Science of Werner Heisenberg*. New York: Freeman, 1993.

de Chadarevian, Soraya. “Using Interviews to Write the History of Science.” In *The Historiography of Contemporary Science and Technology*, edited by Thomas Söderqvist. Studies in the History of Science, Technology, and Medicine, vol. 4. Amsterdam: Harwood Academic Publishers, 1997.

Chandrasekhar, Subramanyan. “Autobiography” http://nobelprize.org/physics/laureates/1983/chandrasekhar-autobio.html (24 Mar 2006). Also in *Lex Prix Nobel*. Edited by Wilhelm Odelberg. Stockholm: Nobel Foundation, 1984.

Chomsky, Noam, Ira Katznelson, R. C. Lewontin, David Montgomery, Laura Nader, Richard Ohmann, Ray Siever, Immanuel Wallerstein, and Howard Zinn. *The Cold War and the University: Toward an Intellectual History of the Postwar Years*. New York: The New Press, 1997.

Christensen, Terry M. “Creating Chains of Wisdom: The Role of Interdisciplinarity in Mentoring.” Master's Thesis, Marylhurst University, 2001.

Christensen, Terry M. “Theoretical Physics Takes Root in America: John Archibald Wheeler as Student and Mentor.” Master’s Thesis, Oregon State University, 2006.

Christodoulou, Demetrios. “Investigations in Gravitational Collapse and the Physics of Black Holes.” Ph.D. Dissertation, Princeton University, 1971.

Clark, Burton R., ed. *The Research Foundations of Graduate Education: Germany, Britain, France, United States, Japan*. Berkeley: University of California Press, 1993.

Collins H. M., “The TEA Set: Tacit Knowledge and Scientific Networks.” *Science Studies* 4 (1974): 165-186.

Collins, Harry. *The Shape of Actions: What Humans and Machines Can Do.* Cambridge, MA: MIT Press, 1998.

Committee on Science, Engineering, and Public Policy (U.S.). *Enhancing the Postdoctoral Experience for Scientists and Engineers: A Guide for Postdoctoral Scholars, Advisers, Institutions, Funding Organizations, and Disciplinary Societies*. Washington, DC: National Academy Press.

Cooke, George Willis. *Unitarianism in America: A History of its Origin and Development*. 1902. Reprint. St. Claire Shores, MI: Scholarly Press, 1969[?].

Cooper, Duncan L. “Variational Properties of Chern’s Invariant Differential Forms.” Senior Thesis [Department of Mathematics], Princeton University, 1965.

Cornell University, Department of Physics, “James W. York, Jr., Professor of Physics” [profpages]. http://www.physics.cornell.edu/profpages/York.htm (25 May 2006).

Crew, Henry. “Joseph Sweetman Ames, 1864 – 1943.” http://books.nap.edu/html/biomems/james.pdf (05 Feb 2009), n.p.. Also in National Academy of Sciences. *Biographical Memoirs,* Vol. 23, 180-201. Washington, DC: National Academies Press, 1944.

Crosland, Maurice. “Research Schools of Chemistry from Lavoisier to Wurtz.” *The British Journal for the History of Science* 36, no. 3 (2003): 333-361.

Cushing, James T. *Philosophical Concepts in Physics: The Historical Relation between Philosophy and Scientific Theories.* Cambridge, UK: Cambridge University Press, 1998.

Dahl, Per. “Breit, Gregory.” In *Complete Dictionary of Scientific Biography,* edited by Charles Gillispie. Vol. 19, 389-393. New York: Cengage Learning, 2008. Gale Virtual Reference Library. Gale. Oregon State University (GVRL). http://find.galegroup.com.proxy.library.oregonstate.edu/gvrl/infomark.do?&contentSet=EBKS&type=retrieve&tabID=T001&prodId=GVRL&docId=CX2830905522&source=gale&userGroupName=corv13107&version=1.0 (04 Feb 2009).

Dalitz R. H. (Richard Henry) and Rudolf Peierls. “Paul Adrien Maurice Dirac, 8 August 1902 – 20 October 1984.” *Biographical Memoirs of Fellows of the Royal Society* 32 (1986): 139-185.

Darling, Karen Merikangas. “Motivational Realism: The Natural Classification for Pierre Duhem.” *Philosophy of Science* 70, No. 5 (Dec 2003): 1125-1136.

Delbrück, Max. “Biography” http://nobelprize.org/medicine/laureates/1969/delbruck-bio.html (24 Mar 06). Also in *Nobel Lectures, Physiology or Medicine 1963-1970*. Amsterdam: Elsevier Publishing Company, 1972.

Department of Commerce (U.S.), Bureau of the Census. *Historical Statistics of the United States: Colonial Times to 1957.* Herman P. Miller, Project Director. Washington, DC: U.S. Government Printing Office, 1960.

Deutsch, David. “On Wheeler’s Notion of “Law Without Law” in Physics.” In *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler* edited by Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller. Princeton, NJ: Princeton University Press. 1988, 583-591.

DeWitt, Bryce, and Cecile DeWitt-Morette. “Interview with Bryce DeWitt and Cecile DeWitt-Morette.” Interview by Kenneth W. Ford. Transcript. Austin, TX, 28 Feb 1995, NBL-AIP.

Doel, Ronald E. “Oral History of American Science: A Forty Year Review.” *History of Science* 41, no. 4 (Dec 2003): 349-378. http://oasis.oregonstate.edu/search/tHistory+of+Science/thistory+of+science/1%2C2%2C2%2CE/c8561053566&FF=thistory+of+science&1%2C1%2C%2C1%2C0 24 June 2006.

“Dr. Gilbert Plass” [Obituary].*The Bryan – College Station Eagle*. http://www.theeagle.com/region/records/obituaries/march2004/030304obits.php (12 Sep 2005).

Drake, Stillman, “Galileo’s Experimental Confirmation of Horizontal Inertia: Unpublished Manscripts.” *Isis* 64 (1973): 291-305.

Drake, Stillman and James MacLachlan. “Galileo’s Discovery of the Parabolic Trajectory.” *Scientific American* 232, no. 3 (Mar 1975): 102-108.

Drake, Stillman. *Galileo: Pioneer Scientist.* Buffalo, NY: University of Toronto Press, 1990.

Duhem, Pierre. *The Aim and Structure of Physical Theory*, 2d ed. Translated by Philip P. Wiener. Princeton: Princeton University Press, 1991. Quoted in Darling, Karen Merikangas. "Motivational Realism: The Natural Classification for Pierre Duhem." *Philosophy of Science* 70, No. 5 (Dec 2003): 1125-1136.

Dupree, A. Hunter. *Science in the Federal Government A History of Policies and Activities to 1940.* Cambridge, MA: Belknap Press of Harvard University Press, 1957. Reprint, Baltimore, MD: Johns Hopkins University Press, 1986.

Edge, David O. and Michael Mulkay. *Astronomy Transformed: The Emergence of Radio Astronomy in Britain.* New York: Wiley, 1976.

Einstein, Albert, Max Born, and Hedwig Born. *The Born-Einstein Letters: Correspondence between Albert Einstein and Max and Hedwig Born from 1916 to 1955. With Commentaries by Max Born.* Translated by Irene Born. New York: Walker and Company, 1971.

Einstein, Albert. *Letters to Solovine.* Trans. by Wade Baskin. New York: Philosophical Library, 1987.

Ernst, Frederick Joseph Jr. "The Wave Functional Description of Elementary Particles with Application to Nucleon Structure." Ph.D. Dissertation, University of Wisconsin, 1958.

Family Gathering: Students and collaborators of John Archibald Wheeler gather some recollections of their work with him, and of his influence on them and through them on their own students, Assembled with the best wishes as John moves on to a new career in Texas. Princeton, NJ: n.p., 1977.

Feibelmen, Peter J. *A Ph.D. is not Enough: A Guide to Survival in Science*. Reading, MA: Addison-Wesley, 1993.

Feynman, Richard P. "Pocono Conference." *Physics Today* 1, no. 2 (Jun 1948): 8-10.

Feynman, Richard P. "Biography" http://nobelprize.org/physics/laureates/1965/feynman-bio.html (24 Mar 06). Also in *Nobel Lectures, Physics 1963-1970*. Amsterdam: Elsevier Publishing Company, 1972.

Feynman, Richard Phillips. "Interview with Richard Feynman". Interview with Charles Weiner. Session 1, 04 Mar 1966, Altadena, CA. NBL-AIP.

Feynman, Richard P. “The Development of the Space-Time View of Quantum Electrodynamics,” Nobel Lecture, 11 December 1965 http://nobelprize.org/physics/laureates/1965/feynman-lecture.html (24 Mar 06). Also in *Nobel Lectures, Physics 1963-1970*. Amsterdam: Elsevier Publishing Company, 1972.

Feynman, Richard P. *QED: The Strange Theory of Light and Matter*. Princeton, NJ: Princeton University Press, 1985.

Feynman, Richard P. and Ralph Leighton. *Surely You’re Joking Mr. Feynman: Adventures of a Curious Character*. New York: W. W. Norton & Co, 1985.

Feynman, Richard P., with Ralph Leighton *What Do You Care What Other People Think: Further Adventures of a Curious Character*. New York: Bantam Books, 1988.

Fine, Arthur. *The Shaky Game: Einstein, Realism, and the Quantum Theory*, 2nd ed. Chicago: University of Chicago Press, 1986.

Fleck, Ludwig. *Genesis and Development of a Scientific Fact*. Translated by Fred Bradley and Thaddeus J. Trenn. Chicago: University of Chicago Press, 1970.

Fogg, Piper. “The Catalytic Mentor: An Award Winning Chemist at Rutgers University Takes Students under Her Wing” [The Faculty]. *The Chronicle of Higher Education* 49, no. 47 (Aug 2003): A-10. http://oasis.oregonstate.edu/search/tThe+Chronicle+of+Higher+Education/tchronicle+of+higher+education/1%2C2%2C5%2CE/c8561056116&FF=tchronicle+of+higher+education&2%2C%2C4%2C1%2C0 (22 Jan 06).

Ford, Kenneth W. “Working (and not Working) on Weapons.” Working paper. Sigma Pi Sigma Congress, Albuquerque, NM, 15 Oct 2004.

Ford, Kenneth W. “Kenneth W. Ford -- Personal Web Page.” http://www.ianford.com/kenford/ (21 Aug 2005).

Forman, Paul, John L. Heilbron, and Spencer Weart. “Physics circa 1900.” *Historical Studies of the Physical Sciences* 5 (1975): 3-185.

Fort, Deborah C., ed. *A Hand Up: Women Mentoring Women in Science.* Washington DC: Association for Women in Science, 1995.

James Franck. "Biography." http://nobelprize.org/nobel_prizes/physics/laureates/1925/franck-bio.html (16 Feb 2009). Also in *Nobel Lectures, Physics 1922-1941*. Amsterdam: Elsevier Publishing Company, 1965.

Frank, Philipp. *Einstein: His Life and Times.* Translated by George Rosen, Edited by Shuichi Kusaka. New York: Alfred A. Knopf, 1947.

French, John Calvin. *A History of the University Founded by Johns Hopkins.* Baltimore, MD: The Johns Hopkins University Press, 1946.

Frisch, Otto and John A. Wheeler. “The Discovery of Fission.” *Physics Today* 20, no. 11 (Nov 1967): 43-52.

Frost, Peter J. and M. Susan Taylor, eds. *The Rhythms of Academic Life: Personal Accounts of Careers in Academia.* Thousand Oaks, CA: Sage Publications, 1996.

Frugoli, Julia A. “Commentary on ‘Mentors, Advisors and Supervisors: Their Role in Teaching Responsible Research Conduct’: It Really Does Take a Village.” *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 469-470.

Fruton, Joseph. “The Liebig Research Group: A Reappraisal.” *Proceedings of the American Philosophical Society* 132 (1988): 1-66.

Fruton, Joseph. *Contrasts in Scientific Style: Research Groups in the Chemical and Biochemical Sciences*. Philadelphia: American Philosophical Society, 1990.

Galilei, Galileo. *On Motion and On Mechanics: Comprising De Motu* (ca.1590) *and Le Meccanishe* (ca.1600). Publications in Medieval Science. Translated by I. E. Drabkin and Stillman Drake. Madison, WI: University of Wisconsin Press, 1960.

Galilei, Galileo. *Il Saggiatore (The Assayer).* Translated by George MacDonald Ross, 1998. http://www.philosophy.leeds.ac.uk/GMR/hmp/texts/modern/galileo/assayer.html (20 May 2005).

Galilei, Galileo. *Dialogue Concerning the Two Chief World Systems* (1632). Translated by Stillman Drake. http://www.law.umkc.edu/faculty/projects/ftrials/galileo/dialogue.html (22 Apr 2006).

Galilei, Galileo. *Dialogues Concerning Two New Sciences* (1638). Translated by Henry Crew and Alfonso de Salvio with an introduction by Antonio Favaro. New York: The MacMillian Co. 1914.

Galison, Peter. *How Experiments End.* Chicago: University of Chicago Press, 1987.

Galison, Peter. "Physics Between War and Peace." In *Science, Technology, and the Military*. Vol. 12, part 1, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988.

Galison, Peter, and Barton Bernstein. "In Any Light: Scientists and the Decision to Build the Super bomb, 1952-1954." *Historical Studies in the Physical and Biological Sciences* 19 (1989): 267-347.

Galison, Peter. *Image and Logic: A Material Culture of Microphysics.* Chicago: University of Chicago Press, 1997.

Galison, Peter. "Material Culture, Theoretical Culture, and Delocalization." In *Science in the Twentieth Century.* Edited by John Krige and Dominque Pestre. Amsterdam: Harwood Academic Publishers, 1997.

Gardenier, John. "Commentary on 'Mentoring and the Impact of the Research Climate' (Roberts, Kavussano and Sprague)" *Mentoring and the Responsible Conduct of Research*. Edited by Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 538-540.

Gearhart, Mirjana R. Forum: John A. Wheeler, "From Big Bang to Big Crunch". *Cosmic Search Magazine* 1, no. 4 (1979) http://www.bigear.org/vol1no4/wheeler.htm (22 Oct 2003).

Gell-Mann, Murray. "Dick Feynman—The Guy in the Office Down the Hall." *Physics Today* 42, no.2 (Feb 1989): 50-54.

Geison, Gerald L., "Scientific Change: Emerging Specialties and Research Schools." *History of Science* 19, Part 1, no. 43 (Mar 1981): 20-40.

Geison, Gerald L. "Research Schools and New Directions in the Historiography of Science." In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993), 227-238.

Geroch, Robert P. “Robert P. Geroch, Curriculum Vitae” http://physics.uchicago.edu/t_rel.html#Geroch (21 Aug 2005).

Gilman, Daniel Coit. *The Launching of a University, and Other Papers: A Sheaf of Remembrances.* New York: Dodd, Mead, & Co., 1906.

Gleick, James. *Genius: The Life and Science of Richard Feynman.* New York: Vintage Books, 1992.

Gleick, James. *Isaac Newton.* New York: Pantheon Books, 2003.

Goeppert-Mayer, Maria. "Biography." http://nobelprize.org/nobel_prizes/physics/laureates/1963/mayer-bio.html (12 Feb 2009). Also in *Nobel Lectures, Physics 1963-1970*. Amsterdam: Elsevier Publishing Company, 1972.

Goldberg, Stanley. “Inventing a Climate of Opinion: Vannevar Bush and the Decision to Build the Bomb.” In *The Scientific Enterprise in America: Readings from Isis*. Edited by Ronald L. Numbers and Charles E. Rosenberg. Chicago: University of Chicago Press, 1996.

Goodstein, David L. “Scientific Ph.D. Problems”. *American Scholar* 62, no.2 (Spr 1993): 215-221. http://0search.epnet.com.oasis.oregonstate.edu:80/login.aspx?direct=true&db=aph&an=9304060251 (05 Jan 2006).

Google Scholar, search author “JA Wheeler”. http://scholar.google.com/scholar?as_q=&num=100&btnG=Search+Scholar&as_epq=&as_oq=&as_eq=&as_occt=any&as_sauthors=%22JA+Wheeler%22&as_publication=&as_ylo=&as_yhi=&as_allsubj=all&hl=en&lr= (23 Nov 2008).

Grant, Peter. *Ecology and the Evolution of Darwin's Finches.* Princeton, NJ: Princeton University Press, 1986.

Green, John C. “A Liberal Dynamo: The Political Activism of the Unitarian Universalist Clergy.” *Journal for the Scientific Study of Religion* 42 [Online], no 4 (Dec 2003): 577-590. Academic Search Premier http://0-web17.epnet.com.oasis.oregonstate.edu/Delivery (07 May 2005).

Greenberger, Daniel M. Preface to “Fundamental Problems in Quantum Theory: A Conference held in Honor of Professor John Archibald Wheeler.” *Annals of the New York Academy of Sciences* 755. Edited by Daniel M. Greenberger and Anton Zeilinger. New York: New York Academy of Sciences, 1995, xiii-xiv.

Grele, Ronald J. “Movement Without Aim: Methodological and Theoretical Problems in Oral History.” In *The Oral History Reader*, edited by Robert Perks and Alistair Thomson. London: Routledge, 1998. Originally published in Ronald J. Grele, *Envelopes of Sound: The Art of Oral History* (Chicago: Precedent Publishing, 1985.

Griffin, James J. “James J. Griffin Curriculum Vitae.” http://www.physics.umd.edu/people/faculty/cv/GriffinCV.pdf (21 Aug 2005).

Griffy, Thomas. “Interview with Tom Griffy.” Interview by Ken Ford. 28 Feb 1995, University of Texas at Austin. Transcript. http://www.aip.org/history/ohilist/23203.html (09 Oct 2008).

Gusterson, Hugh. “A Pedagogy of Diminshing Returns: Scientific Involution across Three Generations of Nuclear Weapons Science.” In *Pedagogy and the Practice of Science.* Edited by David Kaiser. Inside Technology, ed. Wiebe E. Bijker, W. Bernard Carlson, and Trevor Pinch. Cambridge, MA: MIT Press, 2005: 75-108.

Hagen, Joel. “Clementsian Ecologists: The Internal Dynamics of a Research School.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 178-195.

Hahn, Alexander J. “The Pendulum Swings Again: A Mathematical Reassessment of Galileo’s Experiments with Inclined Planes.” *Archive of the History of Exact Sciences* 56 (2002): 339-361.

Hannaway, Owen. “The German Model of Chemical Education in America: Ira Remsen at Johns Hopkins (1876-1913).” *Ambix: The Journal of the Society for the History of Alchemy and Chemistry* 23 (1976): 145-164.

Harmon, Lindsey R. and Herbert Soldz, comps. *Doctorate Production in United States Universities, 1920-1962: With Baccalaureate Origins of Doctorates in Sciences Arts and Professions.* Washington, DC: National Academy of Sciences – National Research Council, 1963.

Hartle, James B. “James B. Hartle's Homepage.” http://www.physics.ucsb.edu/~hartle/ (06 May 2006).

Hawkins, Hugh. *Pioneer: A History of the Johns Hopkins University, 1874-1889.* Baltimore, MD: Johns Hopkins University Press, 2002.

Heilbron, John L. Dilemmas of an Upright Man: Max Planck as Spokesman for German Science. Berkeley, CA: University of California Press, 1986.

Heisenberg, Werner "Biography" http://nobelprize.org/physics/laureates/1932/heisenberg-bio.html (24 Mar 2006). Also in *Nobel Lectures, Physics 1922-1941*. Amsterdam: Elsevier Publishing Co., 1965.

Helmuth, T., H. Walther, A. Zajonc, and W. Schleich. "Delayed Choice Experiments in Quantum Interference." *Physical Review A* 35, no. 6 (Mar 1987): 2532-2541.

Henson, Pamela M. "The Comstock Research School in Evolutionary Entomology." In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 157-177.

Hershberg, James G. " 'Over My Dead Body:' James Bryant Conant and the Hydrogen Bomb." In *Science, Technology, and the Military*. Vol. 12, part 2, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988.

Herzfeld, Karl Ferdinand (1892-1978). "Interview with Dr. Karl Herzfeld." Interview by Bruce Wheaton. 11 May 1978, Washington, DC. Transcript. http://www.aip.org/history/ohilist/4669.html (05 Jan 2009).

Hevesy, George de. "Biography" http://nobelprize.org/chemistry/laureates/1943/hevesy-bio.html (24 Mar 2006). Also in *Nobel Lectures, Chemistry 1942-1962*. Amsterdam: Elsevier Publishing Co., 1964.

Hill, David K. "Dissecting Trajectories: Galileo's Early Experiments on Projectile Motion and the Law of Fall." *Isis* 79, no. 299 (Dec 1988): 646-668.

Hoch, Paul. "The Crystallization of a Strategic Alliance: The American Physics Elite and the Military in the 1940's." In *Science, Technology, andthe Military*. Vol. 12, part 1, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988.

Holmes, F. L. "Justus von Liebig" In *Dictionary of Scientific Biography,* edited by Charles Coulston Gillispie. New York: Scribner and Sons, 1973.

Holmes, Frederic L. “Historians and Contemporary Scientific Biography.” In *The Pauling Symposium: A Discourse on the Art of Biography.* Edited by Ramesh S. Krishnamurthy, Clifford S. Mead, Mary Jo Nye, Sean C. Goodlett, Marvin E. Kirk, Shirley A. Golden, and Lori L. Zielinski. Corvallis, OR: Special Collections, Oregon State University Libraries, 1996.

Holmes, Frederic Lawrence. *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists*. New Haven, CN: Yale University Press, 2004.

Holton, Gerald. “Niels Bohr and the Integrity of Science.” *American Scientist* 74, no. 3 (May-Jun 1986): 237-243.

Holz, Daniel E. “Primal Chaos Black Holes.” Senior Thesis, Princeton University, 1992), n.p. PRIN.

Hookway, Christopher. "Pragmatism." *The Stanford Encyclopedia of Philosophy* (Fall 2008 Edition), edited by Edward N. Zalta. http://plato.stanford.edu/archives/fall2008/entries/pragmatism (15 Feb 2009). Stanford, CA: Stanford University, The Metaphysics Research Lab, Center for the Study of Language and Information.

Hu, Bei-Lok Bernard. “Bei-Lok Bernard Hu, Curriculum Vitae” http://www.physics.umd.edu/people/faculty/cv/HuCV.pdf (22 Aug 2005).

Hull, McAllister, “Gregory Breit: July 14, 1899 – September 11, 1981,” http://www.nap.edu/html/biomems/gbreit.html (08 Dec 03), n.p. Also in National Academy of Sciences*, Biographical Memoirs* Vol 74, 26-57. Washington DC: National Academies Press, 1998.

Isenberg, Jim. “Jim Isenberg,” Curriculum Vitae http://physics.uoregon.edu/~jim/CV.pdf (25 Aug 2005).

Jakubowicz, Oleg George. "A Delayed Random Choice Quantum Mechanics Experiment using Light Quanta." Ph.D. Dissertation, University of Maryland, 1984.

Jaques, Vincent, E. Wu, Frédéric Grosshans, François Treussart, Philippe Grangier, Alain Aspect, Jean-François Roch. "Experimental Realization of Wheeler's Delayed-Choice Gedanken Experiment." *Science* 315, no. 5814 (16 Feb 2007): 966-968.

Johns Hopkins University. “Johns Hopkins Chronology” http://webapps.jhu.edu/jhuniverse/information_about_hopkins/about_jhu/chronology/index.cfm?window=print (06 Jan 2005).

Jungnickel, Christa and Russell McCormmach. *Intellectual Mastery of Nature: Theoretical Physics From Ohm to Einstein.* 2 vols. Chicago: University of Chicago Press, 1986.

Kadel, R. W., et al [433 others], “Observation of Top Quark Production in $p^{-} p$ Collisions with the Collider Detector at Fermilab”, *Physical Review Letters* 74, No. 14 (3 Apr 1995), 2626-2631, http://prola.aps.org/abstract/PRL/v74/i14/p2626_1 (23 Nov 2008).

Kadel R. W., et al [405 others], “Measurement of the W Boson Mass”, *Physical Review D* 52, No. 9 (01 Nov 1995), 4784-4827, http://prola.aps.org/abstract/PRD/v52/i9/p4784_1 (23 Nov 2008).

Kadel, R. W., et al [627 others], “Observation of CP Violation in the B^0 Meson System” *Physical Review Letters* 87, No. 9 (27 Aug 2001), 091801-1 [8 pages], http://prola.aps.org/abstract/PRL/v87/i9/e091801 (23 Nov 2008).

Kaiser, David. “A Ψ is Just a Ψ? Pedagogy, Practice, and the Reconstitution of General Relativity, 1942–1975.” *Studies in History and Philosophy of Modern Physics* 29, No. 3 (Sep 1998): 321–338.

Kaiser, David. “Cold War Requisitions: Scientific Manpower and the Production of American Physicists after World War II.” *Historical Studies in the Physical and Biological Sciences* 33, no. 1 (2002): 131-160.

Kaiser, David. “Nuclear Democracy: Political Engagement, Pedagogical Reform, and Particle Physics in Postwar America,” *Isis* 93, No. 2 (Jun 2002), 229-268.

Kaiser, David. *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics*. Chicago: University of Chicago Press, 2005.

Kaiser, David, ed. *Pedagogy and the Practice of Science*. Inside Technology, ed. Wiebe E. Bijker, W. Bernard Carlson, and Trevor Pinch. Cambridge, MA: MIT Press, 2005.

Kaiser, David. “Whose Mass is it Anyway? Particle Cosmology and the Objects of Theory.” *Social Studies of Science* 36, No. 4 (Aug 2006): 533 – 564.

Kaiser, David. “Training Quantum Mechanics: Enrollments and Epistemology in Modern Physics.” Excerpted from *American Physics and the Cold War Bubble.* Chicago: University of Chicago Press, forthcoming.

Kanigel, Robert. *Apprentice to Genius: The Making of a Scientific Dynasty*. Baltimore, MD: Johns Hopkins University Press, 1986.

Katzen, Brit B. “The Search for Pregeometry: The Work of John Archibald Wheeler.” Senior Thesis [Department of History], Princeton University, 1998.

Keith, S. T., and Paul K. Hoch. "The Formation of a Research School: Theoretical Solid State Physics at Bristol, 1930 – 54." *British Journal for the History of Science* 19, Pt. 1, No. 6 (Mar 1986): 19-44.

Kelly, Shalonda, and John C. Schweitzer. “Mentoring Within a Graduate School Setting.” *College Student Journal* 99, no. 1 (Mar 1999): 130-148, EBSCOhost/Academic Search Elite/AN1713855, (15 Jan 2001).

Kennedy, Donald. *Academic Duty.* Cambridge, MA: Harvard University Press, 1997.

Kevles, Daniel J. *The Physicists: The History of a Scientific Community in Modern America*. New York: Knopf, 1977.

Kevles, Daniel J. “An Analytical Look at R&D and the Arms Race.” In *Science, Technology, and the Military.* Vol. 12, part 2, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988

Kevles, Daniel J. “The National Science Foundation and the Debate over Postwar Research Policy.” In *The Scientific Enterprise in America: Readings from Isis,* edited by Ronald L. Numbers and Charles E. Rosenberg. Chicago: University of Chicago Press, 1996.

King, David H. "Mach's Principle and Rotating Universes." Ph.D. Dissertation, University of Texas at Austin, 1990.

Klauder, John R. “Magic Without Magic: John Archibald Wheeler: An Introduction.” In *Magic Without Magic: John Archibald Wheeler; A Collection of Essays in Honor of His Sixtieth Birthday.* Edited by John R. Klauder. San Francisco: W. H. Freeman, 1972, 1-14.

Knight, Kevin. "Thomism." *The Catholic Encyclopedia*. http://www.newadvent.org/cathen/14698b.htm (15 Feb 2009).

Koyré, Alexandré. *Galileo Studies.* 1939. Reprint, Atlantic Highlands, NJ: Humanities Press, 1978.

Kragh, Helge. *Cosmology and Controversy: The Historical Development of Two Theories of the Universe*. Princeton, NJ: Princeton University Press, 1996.

Kragh, Helge. *Quantum Generations: A History of Physics in the Twentieth Century*. Princeton, NJ: Princeton University Press, 1999.

Kuhn, Thomas S. *The Structure of Scientific Revolutions,* 3rd ed. Chicago: University of Chicago Press, 1962, 1970.

Kushner, David. "Sir George Darwin and a British School of Geophysics." In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 196-224.

Landau, Lev "Biography" http://nobelprize.org/physics/laureates/1962/landau-bio.html (24 Mar 2006). Also in *Nobel Lectures, Physics 1942-1962*. Amsterdam: Elsevier Publishing Co., 1964.

Lattimore, Richmond, trans. *The Odyssey of Homer.* New York: Harper and Row, 1967; Perennial Classics Edition, New York: HarperPerennial, 1999.

Leslie, Stuart W. "Science and Politics in Cold War America." In *The Politics of Western Science, 1640-1990*. Edited by Margaret C. Jacob. Atlantic Highlands, NJ: Humanities Press, 1994.

Lindsay, R. B. "Wood, Robert Williams." *Dictionary of Scientific Biography* Vol. XIV. Edited by Charles Coulson Gillispie. New York: Charles Scribner's Sons, 1976.

Marckworth, M. Louise, ed. *Dissertations in Physics: An Indexed Bibliography of All Doctoral Theses Accepted by American Universities, 1861-1959*. Stanford: Stanford University Press, 1961.

Marsh, Herbert W. and John Hattie. "The Relation Between Research Productivity and Teaching Effectiveness: Complementary, Antagonistic, or Independent Constructs?" *The Journal of Higher Education* 73, no.5 (2002): 603-641.

Marshall, George N. *Challenge of a Liberal Faith.* 3rd ed. Boston: Skinner House – Unitarian Universalist Association, 1991.

Martin, Murray, Norwood Gove, Ruth Gove, Subramanian Raman, and Eugene Merzbacher. “Katharine Way” [Obituary]. *Physics Today* 49, no. 12 (Dec 1996): 75. Academic Search Premier http://0-search.epnet.com.oasis.oregonstate.edu:80/login.aspx?direct=true&db=aph&an=9612171661 (13 Sep 2005).

McInerny, Ralph and John O'Callaghan. "Saint Thomas Aquinas." *The Stanford Encyclopedia of Philosophy* (Fall 2008 Edition), edited by Edward N. Zalta. http://plato.stanford.edu/archives/fall2008/entries/aquinas (15 Feb 2009). Stanford, CA: Stanford University, The Metaphysics Research Lab, Center for the Study of Language and Information.

McMillan, Edwin M. “Early History of Particle Accelerators.” Working Paper. In *Nuclear Physics in Retrospect: Proceedings of a Symposium on the 1930’s.* Edited by Roger H. Stuewer. Minneapolis, MN: University of Minnesota Press, 1979.

Melosh, H. Jay. “H. Jay Melosh, Curriculum Vitae” http://www.lpl.arizona.edu/~jmelosh/Bibliography_vita.doc (20 Aug 05).

Mendelsohn, Everett, Merritt Roe Smith, and Peter Weingart. “Introduction: Science and the Military: Setting the Problem. In *Science, Technology, and the Military.* Vol. 12, part 1, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988.

Miller, Arthur I. “Image and Representation in Twentieth Century Physics.” In *The Modern Physical and Mathematical Sciences.* Edited by Mary Jo Nye, Vol. 5 of *The Cambridge History of Science,* General eds. David C. Lindberg and Ronald L. Numbers. New York: Cambridge University Press, 2003.

Miller, Warner A. “Foundations of Null-Strut Geometrodynamics.” Ph.D. Dissertation, University of Texas at Austin, 1986.

Miller, Warren Allen. “Interview with Warren Miller”. Interview by Kenneth W. Ford. Transcript. Interview at Miller’s home in Albequerque, NM, 27 Feb 1995. NBL-AIP. http://www.aip.org/history/ohilist/23201.html (19 Nov 2008).

Misner, Charles W., Kip S. Thorne, John Archibald Wheeler. *Gravitation.* San Francisco: W. H. Freeman and Co., 1973.

Morrell, J. B. "The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson." *Ambix: The Journal of the Society for the History of Alchemy and Chemistry* 19 (Mar 1972): 1-46.

Morrell, Jack. "W. H. Perkin, Jr., at Manchester and Oxford: From Irwell to Isis." In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 104-126.

Mottelson, Ben R. "Autobiography" http://nobelprize.org/physics/laureates/1975/mottelson-autobio.html (24 Mar 2006). Also in *Les Prix Nobel en 1975*. Edited by Wilhelm Odelberg. Stockholm: Nobel Foundation, 1976.

Mulligan, Joseph F. "Karl Herzfeld, February 24, 1892 – June 3, 1978." http://newton.nap.edu/html/biomems/kherzfeld.html (20 Mar 06), n.p. Also in National Academy of Sciences. *Biographical Memoirs,* Vol. 80, 160-183. Washington, DC: National Academies Press, 2001.

National Academy of Sciences, National Academy of Engineering, Institute of Medicine (U.S.). *Adviser, Teacher, Role Model, Friend: on Being a Mentor to Students in Science and Engineering.* Washinton DC: National Academy Press, 1977 http://oasis.oregonstate.edu/search/cQ181+.A35+1999/cq+++181+a35+1999/-2,-1,0,E/l856~2152434&FF=&1,0,,1,0 (27 Feb 06).

National Institute of Standards and Technology. "NIST at 100: Foundations for Progress." http://www.100.nist.gov/directors.htm (05 Jan 2009).

National Research Council. *A Century of Doctorates: Data Analyses of Growth and Change*. Washington DC: National Academy of Sciences, 1978.

"Niels Bohr" [Obituary]. *Physics Today* 16, no. 1 (Jan 1963): 102.

Niels Bohr Institute for Theoretical Physics. "NBI History." Availble online:http://www.nbi.dk/nbi-history.html#history (23 Apr 2006).

North Dakota State University, Department of Mathematics. "Arthur Strong Wightman." The Mathematics Genealogy Project http://www.genealogy.ams.org/html/id.phtml?id=11904&fChrono=1 (21 Aug 2005).

North Dakota State University, Department of Mathematics. “Francis Dominic Murnaghan.” Mathematics Genealogy Project http://www.genealogy.math.ndsu.nodak.edu/html/id.phtml?id=11540 (21 Mar 2006).

North Dakota State University, North Dakota State University. “Frederick J. Ernst”. Mathematical Genealogy Project. http://genealogy.math.ndsu.nodak.edu/id.php?id=31332 (22 Nov 2008).

Nye, Mary Jo. *Science in the Provinces: Scientific Communities and Provincial Leadership in France, 1860-1930.* Berkeley: University of California Press, 1986.

Nye, Mary Jo. “National Styles? French and English Chemistry in the Nineteenth and Early Twentieth Centuries.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 30-49.

Nye, Mary Jo. “Scientific Disciplines: The Construction of Identity.” Chap. 1 in *From Chemical Philosophy to Theoretical Chemistry: Dynamics of Matter and Dynamics of Disciplines, 1800-1850*. Berkeley, CA: University of California Press, 1993.

Nye, Mary Jo. *Before Big Science: The Pursuit of Modern Chemistry and Physics, 1800-1940.* New York: Twayne Publishers, 1996. Reprint. Cambridge, MA: Harvard University Press, 1999.

O’Connor, J. J. and E. F. Robertson. “Francis Dominic Murnaghan.” MacTutor History of Mathematics, October 2003 http://www-history.mcs.st-andrews.ac.uk/Biographies/Murnaghan.html (21 Mar 2006).

Olesko, Kathryn M. *Physics as a Calling: Discipline and Practice in the Konigsberg Seminar for Physics*. Ithaca: Cornell University Press, 1991.

Olesko, Kathryn M. “Tacit Knowledge and School Formation.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 16-29.

Olesko, Kathryn M. “The Foundations of a Canon: Kohlrausch’s Practical Physics.” In *Pedagogy and the Practice of Science.* Edited by David Kaiser. Inside Technology, ed. Wiebe E. Bijker, W. Bernard Carlson, and Trevor Pinch. Cambridge, MA: MIT Press, 2005.

Oleson, Alexandra, and John Voss, eds. *The Organization of Knowledge in Modern America, 1860-1920.* Baltimore, MD: Johns Hopkins University Press, 1979.

Pais, Abraham. *Subtle is the Lord: The Science and Life of Albert Einstein*. New York: Oxford University Press, 1982.

Pais, Abraham. *Niels Bohr's Times in Physics, Philosophy, and Polity*. New York: Oxford University Press, 1991.

Partridge, R. Bruce. "R. Bruce Partridge, Curriculum Vitae" http://www.haverford.edu/physics-astro/Partridge/cv.html (24 Aug 2005).

Patton, Charles. "The Logical Microstructure of Physical Systems." Senior Thesis, Department of Mathematics, Princeton University, 1972.

Pauli, Wolfgang. "Biography" http://nobelprize.org/physics/laureates/1945/pauli-bio.html (24 Mar 2006). Also in *Nobel Lectures, Physics 1942-1962*. Amsterdam: Elsevier Publishing Co. 1964.

Pauling, Linus "Biography" http://nobelprize.org/chemistry/laureates/1954/pauling-bio.html (24 Mar 2006). Also in *Nobel Lectures, Chemistry 1942-1962*. Amsterdam: Elsevier Publishing Co., 1964.

Pauling, Linus. Papers. Diary, Speech Transcripts, and Letters. Special Collections (Ava Helen and Linus Pauling Papers), Oregon State University Library.

Pickrel, Steven J. "Trapped Surfaces and the Initial Value Problem in Geometrodynamics." Princeton University Senior Thesis, 1972.

Poggendorff, J. C. *Biographisch-Literarisches Handwörtenbuch der Exakten Naterurwissenschaften.* Edited by Prof. Dr. Rudolph Zaunick and Prof. Dr. Hans Salié. Berlin: Akademie-Verlag, 1956.

Poggendorff, J. C. *Biographisch-Literarisches Handwörtenbuch der Exakten Naterurwissenschaften.* Edited by Prof. Dr. Hans Salié. Berlin: Akademie-Verlag, 1967.

Polanyi, Michael. *Science, Faith, and Society*. Chicago: University of Chicago Press, 1964. (Appeared originally in 1945).

Polanyi, Michael. *The Tacit Dimension*. New York: Doubleday, 1966.

Princeton University, Office of Communications. "Battelle to Establish Professorship in Physics." 18 May 2001. http://www.princeton.edu/pr/news/01/q2/0518-battelle.htm (24 Oct 2003).

Princeton University. "Princeton University Senior Theses Catalog Brief Display," http://libweb5.princeton.edu/theses/thesesvw.asp?Lname=&Fname=&Submit=Search&Title1=&Title2=&Title3=&department=PHY&Class=&Adviser= (22 Aug 2005).

Rapp, Carl S. "A Study of the Modern Concept of Limited Warfare." Senior Thesis, Princeton University, 1959 [UT-JAW].

Ravetz, Jerome R. *Scientific Knowledge and its Social Problems.* Oxford: Clarendon Press, 1971.

Redner, Sidney. "Citation Statistics from 110 Years of Physical Review." *Physics Today* 58, No. 6 (Jun 2005): 49-54.

Reinarz, Alice G. and Eric Robert White, eds. *Beyond Teaching to Mentoring*. San Francisco: Jossey-Bass, 2001.

Reingold, Nathan. "Reflections on 200 years of Science in the United States." In *The Sciences in the American Context: New Perspectives,* edited by Nathan Reingold. Washington, DC: Smithsonian Institution Press, 1979.

Rhodes, Richard. *The Making of the Atomic Bomb.* New York: Simon & Shuster, 1987. Reprint. New York: Simon & Schuster, 1995.

Rhodes, Richard. *Dark Sun: The Making of the Hydrogen Bomb.* Sloan Technology Series. New York: Simon & Shuster, 1995. Reprint. New York, Simon & Shuster, 1996.

Roberts, Glyn C., Maria Kavussanu and Robert L. Sprague. "Mentoring and the Impact of the Research Climate." In *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 525-537.

Robinson, I., A. Schild, and E. Schucking. "Relativistic Theories of Gravitation." *Physics Today* 16, no. 8 (Aug 1963): 17-21.

Rocke, Alan J. “Group Research in German Chemistry: Kolbe’s Marburg and Leipzig Institutes.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 51-79.

Rohrlich, Daniel. “Daniel Rohrlich,” Publications http://www.tau.ac.il/~quantum/who-r-we/dr-pub.txt (22 Aug 2005).

Rosenberg, Charles E. “Science in American Society: A Generation of Historical Debate.” In *The Scientific Enterprise in America: Readings from Isis*. Edited by Ronald L. Numbers and Charles E. Rosenberg. Chicago: University of Chicago Press, 1996, 3-20.

Rosenfeld, Leon. “Bohr, Niels Henrik David.” In *Dictionary of Scientific Biography* Vol. II. Edited by Charles Coulston Gillispie. New York: Charles Scribner’s Sons, 1975.

Rothblatt, Sheldon, and Bjorn Wittrock, eds. *The European and American University since 1800: Historical and Sociological Essays*. New York: Cambridge University Press, 1993.

Rowe, David E. “Mathematical Schools, Communities and Networks.” In *The Modern Physical and Mathematical Sciences.* Edited by Mary Jo Nye, 113 – 132, Vol. 5 of *The Cambridge History of Science,* General eds. David C. Lindberg and Ronald L. Numbers. New York: Cambridge University Press, 2003.

Rowland, Henry Augustus. “A Plea for Pure Science” [Address as Vice-President of Section B of the American Association for the Advancement of Science, Minneapolis, MN (15 Aug 1883)]. In *The Physical Papers of Henry Augustus Rowland*. Compiled by A Committee of the Faculty of Johns Hopkins University. Baltimore, MD: Johns Hopkins University Press, 1902. Previously published in *Proceedings of the American Association for the Advancement of Science,* XXXII (1883): 105-126; *Science,* II (1883): 242-250; *Journal of Franklin Institute,* GXVI (1883): 279-299.

Ryan, Will Carson. *Studies in Early Graduate Education, The Johns Hopkins, Clark University, The University of Chicago*. New York: The Carnegie Foundation for the Advancement of Teaching, 1939 [Note: Also listed as Bulletin no. 30].

Sachs, Robert G. "Maria Goeppert-Mayer, 1906 – 1972." In National Academy of Sciences. Biographical Memoirs, Vol.50, n.p.

http://www.physics.ucla.edu/~moszkows/mgm/rgsmgm4.htm. Also in National Academy of Sciences. Biographical Memoirs Vol. 50, 310-329. Washinton, DC: National Academies Press, 1979.

Salk Institute. “Terrence J. Sejnowski.” http://www.salk.edu/faculty/faculty/details.php?id=48 (21 Aug 2005).

Sapolsky, Harvey M. “Academic Science and the Military: The Years Since the Second World War.” In *The Sciences in the American Context: New Perspectives*, edited by Nathan Reingold. Washington, DC: Smithsonian Institution Press, 1979.

Schumacher, Benjamin. "Communication, Correlation, and Complimentarity." Ph.D. Dissertation, University of Texas at Austin, 1990.

Schweber, Silvan S. “The Mutual Embrace of Science and the Military: The ONR and the Growth of Physics in the United States after World War II.” In *Science, Technology, and the Military.* Vol. 12, part 1, of Sociology of the Sciences, edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart. Boston: Kluwer Academic Publishers, 1988.

Schweber, Silvan S. “Theoretical Physics and the Restructuring of the Physical Sciences: 1925-1975.” In *Big Culture: Intellectual Cooperation in Large Scale Cultural and Technical Systems. An Historical Approach.* Proceedings of the International Meeting held in Bellagio “Villa Serbelloni” (September 7-11, 1992). Edited by Guiliana Gemelli. Bologna: Cooperativa Libraria Universitaria Editrice Bologna, 1994.

Schweber, S. S. [Silvan S.]. “Writing the Biography of a Living Scientist: Hans Bethe.” In *The Pauling Symposium: A Discourse on the Art of Biography.* Edited by Ramesh S. Krishnamurthy, Clifford S. Mead, Mary Jo Nye, Sean C. Goodlett, Marvin E. Kirk, Shirley A. Golden, and Lori L. Zielinski. Corvallis, OR: Special Collections, Oregon State University Libraries, 1996.

Schweber, Silvan S. *In the Shadow of the Bomb: Bethe, Oppenheimer, and the Moral Responsibility of the Scientist*. Princeton, NJ: Princeton University Press, 2000.

Schweber, Silvan S. “Quantum Field Theory Form QED to the Standard Model.” In *The Modern Physical and Mathematical Sciences.* Edited by Mary Jo Nye, Vol. 5 of *The Cambridge History of Science,* General eds. David C. Lindberg and Ronald L. Numbers. New York: Cambridge University Press, 2003.

Scott, William T. “Michael Polyani’s Creativity in Chemistry.” Chap. 11 in *Springs of Scientific Creativity: Essays on Founders of Modern Science.* Edited by Rutherford, H. Aris, Ted Davis, and Roger Stuewer. Minneapolis, MN: University of Minnesota Press, 1983.

Sears, Francis W., Mark W. Zemansky, and Hugh D. Young. *University Physics.* 6th ed. Reading, MA: Addison Wesley, 1992.

Segré, Emilio. *From X-Rays to Quarks: Modern Physicists and Their Discoveries.* San Francisco: W. H. Freeman, 1980.

Seitz, Frederick, Erich Vogt, and Alvin Weinberg. “Eugene Paul Wigner, November 17, 1902 – January 1, 1995”. http://www.nap.edu/html/biomems/ewigner.html (19 Nov 2008), n.p. Also in National Academy of Sciences. *Bibliographical Memoirs,* Vol, 74, 364-388*.* Washington, DC: National Academies Press, 1998.

Sejnowski, Terrence J. “Sources of Gravity Waves.” *Physics Today* 27, No. 1 (Jan 1974), 40- 48.

Sejnowski, Terrence. “A Stochastic Model of Nonlinearly Interacting Neurons.” Ph.D. Dissertation, Princeton University, 1978.

Servos, John W. “Research Schools and Their Histories.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 1-15.

Servos, John W. “Mathematics and the Physical Sciences in America.” In *The Scientific Enterprise in America: Readings From Isis.* Edited by Ronald L. Numbers and Charles E. Rosenberg. Chicago: University of Chicago Press, 1996, 141-159.

Shea, Gordon F. *Mentoring: How to Develop Successful Mentoring Behaviors* [Rev. Edn.]. Menlo, Park, CA: Crisp Publications, 1992.

Simpson, James B., comp. *Simpson's Contemporary Quotations*. Boston: Houghton Mifflin, 1988. http://www.bartleby.com/63/96/2596.html (08 Dec 2003).

Singer, S. Fred. “S. Fred Singer, Ph.D., Professional Background” http://www.sepp.org/bios/singer/cvsfs.html (23 Aug 2005).

Slater, John C. “Quantum Physics in America Between the Wars.” *Physics Today* 21 (Jan 1968): 43.

Smarr, Larry and Joseph Smarr. "Larry Smarr's Personal Home Page" http://www.jacobsschool.ucsd.edu/~lsmarr/ (21 Aug 2005).

Smith, David H. "Notes on a Pilgrimage to Science: A Fly on the Wall." *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 615-634.

Sopka, Katherine Russell. *Quantum Physics in America, 1920-1935.* New York: Arno Press, 1980.

"Spectroscopist of the Century ... William F. Meggers." *Arcs & Sparks* (21 Nov 2002) http://www.cstl.nist.gov/acd/839.01/meggers.html (20 Mar 2006).

Stanford University. SLAC-SPIRES HEP Database of Citation Distribution (01 Dec 2005). http://www.slac.stanford.edu/spires/play/citedist/ (14 Jul 2008).

Stern, Otto. "Biography." http://nobelprize.org/nobel_prizes/physics/laureates/1943/stern-bio.html (06 Jan 2009). Also in *Nobel Lectures, Physics 1942-1962*. Amsterdam: Elsevier Publishing Company,1964.

Swazey, Judith P. "Graduate Students and Mentors: The Need for Divine Intervention: Commentary on 'Mentoring: Some Ethical Considerations' (Weil)." *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 483-485.

Taylor, Edwin F. "The Anatomy of Collaboration." In *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday.* Edited by John R. Klauder. San Francisco: W. H. Freeman, 1972: 474-485.

Teitelboim, Claudio "The Hamiltonian Structure of Spacetime." Ph.D. dissertation, Princeton University, 1973, 105, PRIN.

Templin, Mark A. "A Locally Based Science Mentorship Program for High Achieveing Students: Unearthing Issues that Influence Effective Outcomes." *School Science and Mathematics* 99, no. 4 (Apr 1999): 205-212. EBSCOhost/Academic Search Elite/AN1877598 (15 Jan 2001).

The Enrico Fermi Award - A Presidential Award. Updated November 2001. http://www.pnl.gov/fermi/citations/wheeler-cit.html. (25 Oct 2003).

The Royal Society Library and Archives - List of Fellows. (n.d.) http://www.royalsoc.ac.uk/library/fellows/w.htm. (25 Oct 2003).

Thomson, Willam. “Scientific Laboratories.” *Nature* 31 (Nov 1884 – Apr 1885): 409-413.

Thorne, Kip S. “Nonspherical Gravitational Collapse: A Short Review.” In *Magic Without Magic: John Archibald Wheeler: A Collection of Essays in Honor of His Sixtieth Birthday.* edited by John R. Klauder. San Francisco: W. H. Freeman, 1972: 231-258.

Thorne, Kip S. and Wojciech H. Zurek “John Archibald Wheeler: A Few Highlights of His Contributions to Physics.” In *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler* edited by Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller. Princeton, NJ: Princeton University Press. 1988, 3-13.

Thorne, Kip S. *Black Holes and Time Warps: Einstein's Outrageous Legacy*. New York: W. W. Norton & Co., 1994.

Toll, John Sampson. “John Sampson Toll, Curriculum Vitae.” http://www.physics.umd.edu/people/faculty/cv/TollCV.pdf (21 Aug 2005).

Turner, R. Steven. “Vision Studies in Germany: Helmholtz versus Hering.” In *Research Schools: Historical Reappraisals.* Edited by Gerald L. Geison and Frederic L. Holmes. *Osiris*, 2d ser., vol. 8 (1993): 80-103.

Uchii, Soshichi. “John Archibald Wheeler”. *Gallery of Philosophy and History of Science*. Kyoto University. 01 Oct 02 http://www.bun.kyoto-u.ac.jp/phisci/Gallery/wheeler_note.html. (23 Oct 2003).

Unitarian-Universalist Congregation of Princeton. “The History of UUCP.” http://www.uuprinceton.org/historyuucp.htm (25 May 2005).

University of Maryland. “John Sampson Toll, Curriculum Vitae.” http://www.physics.umd.edu/people/faculty/cv/TollCV.pdf (21 Aug 2005).

Urey, Harold C. “Biography.” http://nobelprize.org/chemistry/laureates/1934/urey-bio.html (24 Mar 2006). Also in *Nobel Lectures, Chemistry 1922-1941*. Amsterdam: Elsevier Publishing Co., 1966.

Vajk, J. Peter, "The Theory of Spherically Symmetric Spacetimes: A New Forumlation." Ph.D. Dissertation, Princeton University, 1968, v, PRIN.

Van De Mark, Brian. *Pandora's Keepers: Nine Men and the Atomic Bomb*. Boston: Little, Brown, and Co., 2003.

Veysey, Laurence R. *The Emergence of the American University*. Chicago: University of Chicago Press, 1965.

Vitale, Bruno, ed. *The War Physicists: Documents about the European Protest Against the Physicists Working for the American Military Through the JASON Division of the Institute for Defense Analysis (IDA), 1972*. Naples : Istituto di Fisica Teorica, 1976.

Wald, Robert M. "Robert M. Wald, Curriculum Vitae" http://physics.uchicago.edu/t_rel.html#Wald (21 Aug 2005).

Warwick, Andrew. *Masters of Theory: Cambridge and the Rise of Mathematical Physics*. Cambridge: Cambridge University Press, 2003.

Washington College. "Meet the Administration: John S. Toll." http://faculty.washcoll.edu/admin_bios/toll.html (26 May 2006).

Weart, Spencer R. "The Physics Business in America, 1919 – 1940: A Statistical Reconnaissance." In *The Sciences in the American Context: New Perspectives,* edited by Nathan Reingold. Washington, DC: Smithsonian Institution Press, 1979.

Weber, Max. *From Max Weber, Essays in Sociology.* Translated and Edited by H. H. Gerth and C. Wright Mills. London: Routledge and Kegan Paul, 1948.

Weil, Vivian. "Mentoring: Some Ethical Considerations." *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 471-482.

Weinberg, Steven. "Autobiography." http://nobelprize.org/nobel_prizes/physics/laureates/1979/weinberg-autobio.html (05 Mar 2009). Also in Stig Lundqvist, ed. *Nobel Lectures, Physics 1971 – 1980*. Singapore: World Scientific Publishing, 1992.

Wheeler, John Archibald. "Wheeler John Archibald, 1911 – 2008 ." Interview by Thomas S. Kuhn and John L. Heilbron. Transcript [partial transcript, neither full transcipt nor tape recording survive.]. Berkeley, CA, 24 March 1962. NBL-AIP, History of Quantum Physics Project.

Wheeler, John A. " 'No Fugitive and Cloistered Virtue' – A Tribute to Niels Bohr." *Physics Today,* 16 no. 1 (Jan 1963): 30-32.

Wheeler, John Archibald. "Niels Bohr and Nuclear Physics" [Talk delivered at Niels Bohr Memorial Session, American Physical Society Conference in Washington, DC on 22 April, 1963] *Physics Today* 16, no. 10 (Oct 1963): 36-46.

Wheeler, John Archibald. "Wheeler, John Archibald, 1911 – 2008." Interview by Charles Weiner and Gloria Lubkin. Transcript. Princeton, NJ, 05 April 1967. NBL-AIP. Call number [OH537].

Wheeler, John Archibald. *Einsteins Vision: Wie steht es heute mit Einsteins Vision, alles als Geometrie aufzufassen?* Berlin: Springer-Verlag, 1968.

Wheeler, John Archibald. "Karl Herzfeld" [Obituary]. *Physics Today* 32, no.1 (Jan 1979): 99.

Wheeler, John A. "Black Hole: An Imaginary Conversation with Albert Einstein." In *Albert Einstein: His Influence on Physics, Philosophy, and Politics.* Edited by Peter C. Aichelburg and Roman U. Sexl. Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979.

Wheeler, John A. "Mercer Street and other Memories." In *Albert Einstein: His Influence on Physics, Philosophy, and Politics.* Edited by Peter C. Aichelburg and Roman U. Sexl. Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979.

Wheeler, John Archibald. "A Decade of Permissiveness" [letter to William Carey, American Association for the Advancement of Science]. *The New York Review of Books* 26 no. 8 (17 May 79). http://www.nybooks.com/articles/7813 (23 Oct 2003).

Wheeler, John Archibald. "Some Men and Moments in the History of Nuclear Physics: The Interplay of Colleagues and Motivations." In *Nuclear Physics in Retrospect: Proceedings of a Symposium on the 1930's.* Edited by Roger H. Stuewer. Minneapolis, MN: University of Minnesota Press, 1979: 217-284.

Wheeler, John A. “Einstein and Other Seekers of the Larger View.” *Science and Public Policy* 6 (Dec 1979): 396-404.

Wheeler, John Archibald. “Einstein: His Strength and His Struggle.” Working Paper. Twentieth Selig Brodetsky Memorial Lecture, University of Leeds, 8 May 1979. Leeds, UK: Leeds University Press, 1980.

Wheeler, John Archibald. “Albert Einstein March 14, 1879 – April 18, 1955.” In National Academy of Sciences. *Biographical Memoirs,* Vol. 51. Washington, DC: National Academy of Sciences, 1980.

Wheeler, John Archibald, and Wojciech Hubert Zurek. *Quantum Theory and Measurement.* Princeton, NJ: Princeton University Press, 1984.

Wheeler, John Archibald. “Niels Bohr, the man.” *Physics Today* 38, no. 10 (Oct 1985): 66-72.

Wheeler, John A. Foreword to *The Anthropic Cosmological Principle,* by John D. Barrow and Frank J. Tipler. New York: Oxford Unversity Press, 1986.

Wheeler, John Archibald. “Herman Weyl and the Unity of Knowledge.” *American Scientist* 74, no. 4 (Jul-Aug 1986): 366-375.

Wheeler, John Archibald. “Wheeler, John Archibald 1911 – 2008.”Interview by Finn Aaserud. Transcript. Princeton, NJ, 04 May and 28 November 1988. NBL-AIP. Call number [OH30194].

Wheeler, John Archibald. “The Young Feynman.” *Physics Today* 42, no.2 (Feb 1989): 24-28.

Wheeler, John Archibald. *A Journey into Gravity and Spacetime*. New York: Scientific American Library, 1990.

Wheeler, John Archibald. “The Young Feynman.” In *“Most of the Good Stuff:” Memories of Richard Feynman.* Edited by Laurie M. Brown and John S. Rigden. New York: American Institute of Physics, 1993, 19-32.

Wheeler, John Archibald. “Wheeler, John Archibald, 1911 – 2008.” Interview by Kenneth W. Ford. Transcript. Princeton, NJ and Meadow Lakes, NJ, 06 Dec 1993 – 18 May 1995. NBL-AIP.

Wheeler, John Archibald and Kenneth Ford. *Geons, Black Holes, and Quantum Foam: A Life in Physics*. New York: W. W. Norton, 1998.

Whitbeck, Caroline. “Group Mentoring to Foster the Responsible Conduct of Research.” *Mentoring and the Responsible Conduct of Research*. Edited By Stephanie J. Bird and Robert L. Sprague. Special Issue: *Science and Engineering Ethics* 7, no. 4 (Jul 2001): 541-558.

Whitehead, Alfred North. *Science in the Modern World: The Lowell Lectures, 1925.* New York: The Macmillan Co, 1925; Reprint, New York: The Free Press, 1967.

Wigner, Eugene Paul. “Interview with Eugene Wigner”. Interview by Lillian Hoddeson, Gordon Baym, and Frederick Seitz. Transcript. New Yorker Hotel, New York, NY, 24 Jan 1981. NBL-AIP. http://www.aip.org/history/ohilist/4965.html (19 Nov 2008).

Wigner, Eugene Paul, with Andrew Szanton. *The Recollections of Eugene P. Wigner as told to Andrew Szanton*. New York: Plenum Press, 1992.

Wooters, William K. “The Acquisition of Information from Quantum Measurements.” Ph.D. dissertation, University of Texas at Austin, 1980.

Wright, Conrad. *Congregational Polity: A Historical Survey of Unitarian and Universalist Practice.* Boston: Skinner House Books, 1997.

York, Herbert F. *Arms and the Physicist*. Masters of Modern Physics. Edited by Robert N. Ubell. Woodbury, NY: American Institute of Physics Press, 1995.

Yukawa, Hideki. *Creativity and Intuition: A Physicist Looks at East and West.* Translated by John Bester. Tokyo: Kodansha International, Ltd., 1973.

Zachary, Lois J. *The Mentor's Guide: Facilitating Effective Learning Relationships.* San Francisco: Jossey-Bass, 2000.

Zimm, Bruno H. “Joseph Edward Mayer (February 5, 1904 – October 15, 1983).” http://books.nap.edu/openbook.php?record_id=4548&page=210 (16 Feb 2009). Also in National Academy of Sciences. *Biographical Memoirs* V 65 (1994), 210-221. Washington, DC: National Academies Press, 1994).

Zuckerman, Harriet. *Scientific Elite: Nobel Laureates in the United States*. New York: The Free Press, 1977. Reprint with a new introduction by the author, New Brunswick, NJ: Transaction Publishing. 1996.

Zurek, Wojciech Herbert, Alwyn van der Merwe, and Warner Allen Miller, eds. *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler*. Princeton, NJ: Princeton University Press, 1988.

APPENDICES

Appendix A: Timeline of John Archibald Wheeler's Life and Works[477]

Year	Month, Day, Event(s)
1911	09 Jul – John Archibald Wheeler born (Jacksonville, FL)
1912	Sep – Family Moves to Glendale CA
1914	10 Aug – Brother Joseph Towne Wheeler born
1915	ca Feb-Father loses position in L.A. Library; (Apr) obtains position with American Library Association managing Library Exhibit at San Francisco World's Fair; later accepts position as director of Youngstown, OH library; Sept – family reunited in Youngstown by way of Washington DC;
1917	16 Apr – Brother Robert Reid Wheeler born; Joseph Wheeler on leave from Youngstown Library for Library War Service position as Armed Forces Librarian 01 Sep – Move to DC to live with mother's parents
1918	Jun – Joseph Wheeler's war service ends; Wheeler family moves back to Youngstown 19 Nov – Sister Mary Bethel Wheeler born
1921	04/01 – Joseph Wheeler takes sabbatical to recover from Scarlet Fever – Family moves to Benson, VT for 1.5 years; in that time span, John Wheeler completes grades 4 – 7 in a one-room Benson, VT schoolhouse.
1922	15 Oct – End of Benson stay; JAW, now 11, works at 8th grade level

[477] I am indebted to Kenneth Ford for sharing an early version of this timeline with me. This timeline also incorporates material from Kip S. Thorne and Wojciech H. Zurek, "John Archibald Wheeler: A Few Highlights of His Contributions to Physics," in *Between Quantum and Cosmos: Studies and Essays in Honor of John Archibald Wheeler,* ed. Wojciech Hubert Zurek, Alwyn van der Merwe, and Warner Allen Miller (Princeton, NJ: Princeton University Press 1988), 3-13. This timeline also incorporates archival source material from APS-JAW, PRIN, PRIN-PHY, UT-JAW, UT-PCL and *Family Gathering.* See also Wheeler and Ford, *Geons,* 65 – 84.

Year	Month, Day, Event(s)
1926	14 Feb – Grandfather Frederick William Archibald dies; Joseph Wheeler becomes Director of Enoch Pratt Free Library, Baltimore, MD; JAW does last year of HS there (Baltimore City College)
1927	JAW enters Johns Hopkins on scholarship as engineering major
1928	Summer in Mexico working for uncle repairing electric motors used in mining operation; engineering beginning to fade – physics seems more interesting
1929	[Hubble's law][478]
1931	JAW has summer work with William Meggers at NBS; publishes first paper with Meggers (on spectroscopy)[479]
1933	Three papers; including, "Dispersion and Absorption in Helium" (1st solo paper)[480] Ph.D. Johns Hopkins at age 21; JAW awarded Rockefeller post-doc; Sep – JAW to NYU to work with Gregory Breit
1934	Three papers; Engaged to Janette Hegner (after three dates) Sep – JAW to Copenhagen to work with Bohr
1935	Two papers; 10 Jun – John and Janette married in Baltimore Sept – JAW begins career at University of North Carolina
1936	Four papers; 30 Jul – daughter Letitia born 15 Dec – JAW on short leave (3 mos.) to Institute for Advanced Study

[478] Bracketed passages (e.g. [Hubble's Law]) are those events which, while not directly impacting John Wheeler, serve to contextualize the zeitgeist in which he worked.
[479] See Appendix B, Item 1.
[480] See Appendix B, Item 2. From this point forward, this appendix will only list those Wheeler publications that have met citation thresholds for significance. These will be noted with a boldface "R" for Renowned (i.e. more than 500 citations); a boldface "F" for Famous (i.e. from 250 – 499 citations); and a boldfaced "VWK" for Very Well-Known (i.e. from 100 – 249 citations).

Year	Month, Day, Event(s)
1937	4 papers; including, “Molecular Viewpoints in Nuclear Structure” (**VWK**) 15 Mar – Return from Institute for Advanced Study to UNC
1938	One paper; 05 May – son James English (Jamie) born [24 Dec – Frisch and Meitner "discover" fission] Katharine Way earns Ph.D. from University of North Carolina JAW hired for Spring Semester at Princeton JAW appointment at Princeton extended to three years
1939	Three papers; including, Bohr – Wheeler “Mechanism on Nuclear Fission” (**R**) 16 Jan – Bohr arrives in NY with Rosenfeld; met by JAW and Fermis at dock; Rosenfeld describes fission at Princeton Journal Club; ca 20 Jan – Bohr asks JAW to collaborate on nuclear fission paper. 26 Jan – Bohr announces fission at George Washington U in DC [16 Jul; 30 Jul – Szilard and Wigner visit Einstein on Long Island] [15 Aug – Einstein letter for Roosevelt sent to Sachs] 01 Sep – Bohr-Wheeler paper published in Phys Rev; same issue contains Oppenheimer-Snyder paper on Gravitational Collapse of Stars into singularity; [War in Europe begins]; JAW’ first house on Battle Road (Princeton) finished [11 Oct – Sachs presents Einstein letter to Roosevelt]
1940	Two papers
1941	Four papers [25 Feb – Seaborg, Kennedy, Wahl discover plutonium] [Oct – Roosevelt approves full-scale effort on bomb] [12/07 – Pearl Harbor]
1942	Two papers [Jan – Lawrence secures microgram quantities of U_{235}] Jan – JAW to Chicago to work with Fermi on reactor development Richard Feynman earns Ph.D. from Princeton.

Year	Month, Day, Event(s)
1943	Three papers Mar – JAW moves to Wilmington work with DuPont (Reactor Design) Apr – Construction starts on Hanford reactor Jun – Construction starts on gaseous diffusion facility at Oak Ridge Nov – micrograms of Plutonium-239 available from Berkeley Cyclotron Nov – Clinton Works TN (Oak Ridge) reactor goes critical
1944	Apr – grams of Pu_{239} available from Clinton Jun – Decision at Project Y to push implosion July – move to Richland Sept – first Hanford pile goes critical 25 Oct – Brother Joe killed in Italy ca Oct – Japanese fire balloons land at Hanford - reactor shuts down
1945	One paper; including Feynman, “Interaction with the Absorber as Mechanism of Radiation” (**F**) Jan – kilogram of Pu_{239} from Hanford 15 Jul – Trinity test [06 Aug – Hiroshima] 09 Aug – Nagasaki
1946	Five papers; Including, “Polyelectrons” (**VWK**)
1947	Five papers; Gilbert Plass earns Ph.D.
1948	Three papers 03 Mar – Granted AEC Q clearance No. 18867 15 Mar – small ONR contract 29 Mar – $375,000 ONR contract to Princeton for cosmic-ray lab ca June – JAW appointed to Reactor Safeguards Committee 11 Aug – Cosmic ray lab up and running with 10 full time researchers

Year	Month, Day, Event(s)
1949	Book: *Elementary Particle Physics* Ten papers; including, Wheeler Feynman, “Classical Electrodynamics in Terms of Direct Interparticle Action.” (**F**) 13 Jan – Guggenheim Fellowship award 13 Jun – Princeton grants 1-year leave at half pay 27 Jun – Reactor Safeguards Committee appointment renewed 04 Jul – Bohr acknowledges receipt of paper on model of nucleus from JAW with Bohr as coauthor 29 Jun – Wheeler family sail for Europe ca Jul – settle in St. Jean de Luz for summer [29 Aug – Joe 1, (Soviet nuclear weapon test)] 03 Sep – Truman announces Joe 1 03 Sep – JAW sends update material to Bohr for joint paper ca Sept or Oct – Reactor Safeguards Committee meets in England ca 15 Sep – JAW visits Copenhagen [30 Oct – GAC of AEC recommends against H-bomb crash program] ca Oct – Smythe and Teller invite JAW to Los Alamos 12 Dec – JAW writes to Bohr about explanation of large nuclear deformations, proposes January visit to Copenhagen 24 Dec – Bohr acknowledges importance of Wheeler idea and confirms invitation for January S. Fred Singer and Thomas Coor earn Ph.D.s

Year	Month, Day, Event(s)
1950	Two papers; 31 Jan – Truman announces crash program for super (H-Bomb) 25 Jan – JAW to Manchester to see cosmic-ray work 27 Jan – JAW to Copenhagen for about a week Feb – JAW goes ahead to Los Alamos, family stays in France Feb – Ulam-Everett develop pessimistic calculation on super [02 Feb – Klaus Fuchs treason revealed] Apr – JAW and David Hill meet Bohr in Princeton Apr – "early 50" Family Committee formed with Teller as chair 20 Apr – Princeton extends JAW leave of absence to 06/30/51 for work on Super 12 Jun – Du Pont asked to build tritium producing reactor in South Carolina [25 Jun – Korean war begins] 30 Jun – Greenhouse test planning begins 10 Sep – GAC receives Teller-Wheeler report on state of bomb theory and negative results by Ulam-Fermi and Ulam-Everett Oct – Teller advocates new lab ca Oct or Nov – JAW begins to think about satellite lab in Princeton 02 Dec – GAC report projects super a long way away Arthur S. Wightman earns Ph.D.
1951	One paper; ca Jan – Lyman Spitzer visits Los Alamos with idea for controlled thermonuclear reaction – fusion power Feb – Planning for Matterhorn; Bradbury (Los Alamos director) reportedly disapproves 23 Feb – Ulam idea for Super; Teller modifies March – Teller-Ulam report 01 Apr – "new super" drafted by Freddie de Hoffman for Teller ca 25 Apr – Greenhouse test successful Apr – Project Matterhorn organized Fall – Teller quits Los Alamos, goes to Chicago 03 Oct – Joe 2 announced 22 Oct – Joe 3 test 13 Dec – GAC meeting, Teller makes case for new lab David Hill earns Ph.D.

Year	Month, Day, Event(s)
1952	29 Oct – JAW studies Oppenheimer-Volkoff and Oppenheimer-Snyder papers on gravitational collapse 14 Apr – Shenstone authorizes 1/4 time appt for 52-53 06 May – Physics chair Shenstone gives JAW "great news" that he can teach relativity course in the fall Sept – JAW spends 1 week in Los Alamos Sept – JAW inaugurates relativity course 32 Oct – [01 Nov on Enewetok] Successful Mike test – 10.4 MT John Toll earns Ph.D.
1953	Four papers; including, Hill – Wheeler, “Nuclear Constitution and the Interpretation of Fission Phenomena.” (**R**) note w/o Bohr Ken Ford earns Ph.D.
1954	Four papers;
1955	Five papers; including, “Geons.” (**VWK**)
1956	Eight papers; Jan-Sept – JAW receives Lorentz professorship in Leiden David Chase, Jim Griffin , and Arthur Komar earn Ph.D.s
1957	12 papers (!); including, Griffin and Wheeler, “Collective Motions in Nuclei by the Method of Generator Coordinates” (**VWK**); JAW, “Assessment of Everett's ‘Relative State’ Formulation of Quantum Theory” (**VWK**); and JAW, “On the Nature of Quantum Geometrodynamics” (**VWK**) Oct-Dec – JAW begins push for national defense lab Charles Misner and Hugh Everett earn Ph.D.s
1958	Three papers; Summer Project 137 (forerunner of Project JASON) begins
1959	Four papers; including K. Ford – Wheeler “Semi-Classical Description of Scattering” (**VWK**) John R. Klauder, B. Kent Harrison, John Fletcher, Robert Euwema & Dieter Brill all earn Ph.D.s
1960	Three papers; Jan-Sept – visiting professorship at UC Berkeley First Jason study group, in Berkeley 20 Dec – Mother Mabel Archibald Wheeler dies Peter Putnam earns Ph.D.

Year	Month, Day, Event(s)
1961	Nine papers; including Baierlein, Sharp and Wheeler, “Three Dimensional Geometry as Carrier of Information about Time” (**VWK**) May – daughter Letitia marries Charles Ufford Robert Fuller, Masami Wakano, and Daniel Sperber earn Ph.D.s
1962	Book: *Geometrodynamics* (**F**) Twelve papers; Richard Lindquist and Fred Manasse earn Ph.D.s
1963	Book: *Spacetime Physics* with Taylor (**F**) Eleven papers; 02/07 – Congressional testimony on nuclear testing Joseph Ball earns Ph.D.
1964	Seven papers Hugh Dempster earns Ph.D.
1965	Book: *Gravitation Theory and Gravitational Collapse*, w/ Harrison, Thorne and Wakano Five papers; Larry Shepley and Kip Thorne earn Ph.D.s
1966	Six papers; JAW serves as president of American Physical Society 25 Jun – son Jamie marries Jenette (Gee) McGehee
1967	Book: *Gravitation Theory and Gravitational Collapse* published in USSR; Nine papers; JAW chairs American Insitute of Physics Committee on Physics and Society (COMPAS) Published talk: The End of Time Robert Geroch earns Ph.D.
1968	Book: *Einsteins Vision* (in German) Six papers; JAW wins Fermi Award Ulrich Gerlach and J. Peter Vajk earn Ph.D.s
1969	Book: *Spacetime Physics* w/ Taylor published in USSR Five papers Robert Fischer, Arthur Gilman, and Frank Zerilli earn Ph.D.s

Year	Month, Day, Event(s)
1970	Book: *Spacetime Physics* w/ Taylor published in France Book: *Einstein's Vision* published in USSR Three papers Dec – Father Joseph Lewis Wheeler dies Brendan Godfrey earns Ph.D.
1971	Book: *Gravitation* with Misner and Thorne (prelim edn.) Nine papers; including Ruffini and Wheeler, ""Introducing the Black Hole" (**VWK**) Demetrious Christodoulou, Clifford Rhoades, and William Unruh earn Ph.D.s
1972	Five papers; Jacob Bekenstein, Bei-Lok Hu, Bahram Mashoon and Robert Wald earn Ph.D.s
1973	Book: *Gravitation* with Misner and Thorne [final] (**R**) Three papers; Two reprints of earlier papers w/ Feynman Claudio Bunster (né Teitelboim) earns Ph.D.
1974	Book: *Black Holes, Gravitational Waves, and Cosmology*, w/ Rees and Ruffini Book: *Spacetime Physics* w/ Taylor published in Hungary Three papers; Lawrence Ford earns Ph.D.
1975	Book: *Spacetime Physics* w/ Taylor published in Poland Six papers; George Kerlick earns Ph.D.
1976	Four papers; Sept. – Move to Texas
1977	Eleven papers; 31 Oct – Brother Rob dies at age 60
1978	Four papers
1979	Book: *Frontiers of Time* Thirty-six papers [Einstein centenary]; One reprint of Nuclear Fission paper w/ Bohr
1980	Nine papers

Year	Month, Day, Event(s)
1981	Book: *Spacetime Physics* w/ Taylor published in Japan Six papers; Jonathan Pfautsch (Texas) earns Ph.D.
1982	Book: *Physics and Austerity* published in China Four papers
1983	Book: *Quantum Theory and Measurement* w/ Zurek Ten papers;
1984	Nine papers;
1985	Fifteen papers [Bohr centenary]
1986	Ten papers; Jul – Retired from Texas but remained in Austin for half a year Arkady Kheyfets and Warner Miller earn Ph.D.s
1987	Five papers; including, “Superspace and the Nature of Quantum Geometrodynamics” (**VWK**) Late Feb/early March – returned to Princeton (Hightstown, NJ)
1988	Eleven papers
1989	Three papers
1990	Book: *Journey into Gravity and Spacetime* Five papers; including, “Information, Physics, Quantum: The Search for Links” (**VWK**) Benjamin Schumacher (Texas) earns Ph.D.
1991	Book: *Spacetime Physics*, with Taylor, second edition Nine papers;
1992	Two papers Daniel E. Holz (AB Princeton 1992) is JAW’s last advisee of record
1993	Three papers
1994	Book: *At Home in the Universe*
1995	Book: *Gravitation and Inertia* w/ Ciufolini (**F**)
1998	Book: *Geons* w/ Ken Ford
1999	One paper

Year	Month, Day, Event(s)
2001	Two papers
2002	One paper
2008	13 Apr – John Archibald Wheeler dies (Hightstown, NJ)

Appendix B: Bibliography of John Archibald Wheeler[481]

Patents:

Neutronic reactor. U.S. Patent 2,782,158. February 19, 1957.

Means for cooling reactors. U.S. Patent 2,812,304. November 5, 1957.

Neutronic reactor. U.S. Patent 2,976,227. March 21, 1961.

Publications:

1. Meggers. W. F., and J. A. Wheeler[482]. "The Band Spectra of Scandium-, Yttrium-, and Lanthanum Monoxides." *National Bureau of Standards Journal of Research* 6, (1931): 239 – 275.

2. Wheeler, John A. "Theory of the Dispersion and Absorption of Helium." *Physical Review* 43, No. 4 (15 Feb 1933): 258 – 263.

3. Bearden, J. A., and J. A. Wheeler. “Determination of *e* or *λ* by Dispersion of X-Rays.” *Physical Review* 43, No. 12 (15 Jun 1933):1059.

4. Wheeler, John A., and G. Breit. “Li^+ Fine Structure and Wave Functions near the Nucleus.” *Physical Review* 44, No. 11 (01 Dec 1933): 948.

5. Wheeler, John A. “Interaction Between Alpha Particles,” *Physical Review* 45, No. 10 (15 May 1934): 746.

6. Wheeler, J. A., and J. A. Bearden. “The Variation of the K Resonating Strength with Atomic Number.” *Physical Review* 46, 755—58 (01 Nov 1934).

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[481] I am indebted to former Wheeler students Ken Ford and Jim Hartle who each were willing to share versions of John Wheeler’s bibliography with me. Even with our combined efforts however, it is likely that some of Wheeler’s work, particularly those works published in foreign journals, have eluded detection to date.

[482] To the extent possible, I have included Wheeler’s name as it was listed on the publication as well as the names of other authors in order to document the number of collaborative publications in Wheeler’s career. I have also boldfaced the names of Wheeler’s former students in order to highlight his collaborative endeavors with them.

7. Breit, G., and J. A. Wheeler, "Collision of Two Light Quanta," *Physical Review* 46, No. 12 (15 Dec 1934): 1087 – 1091.

8. Plesset, Milton S., and John A. Wheeler. "Inelastic Scattering of Quanta with Production of Pairs." *Physical Review* 48, No. 4 (15 Aug 1935): 302 – 306.

9. Yost, F. L., John A. Wheeler, and G. Breit. "Coulomb Wave-Functions." *Terrestrial Magnetism and Atmospheric Electricity* [Now *Journal of Geophysical Research*] 40, No. 4 (1935): 443 – 447.

10. Yost, F. L., John A. Wheeler, and G. Breit. "Coulomb Wave Functions in Repulsive Fields." *Physical Review* 49, No. 2 (15 Jan 1936): 174 – 89.

11. Wheeler, John A. "Cross-Section for the Production of Triples" [Abstract]. *Physical Review* 49, No. 2 (15 Jan 1936): 197.

12. Wheeler, John Archibald. "The Dependence of Nuclear Forces on Velocity." *Physical Review* 50, No. 7 (01 Oct 1936): 643 – 649.

13. **Way, K**., and John A. Wheeler. "Comparison of Majorana-Heisenberg and Velocity-Dependent Forces." *Physical Review* 50, No. 7 (01 Oct 1936): 675.

14. **Way, Katherine**, and John A. Wheeler. "Photoelectric Cross-Section of the Deuteron." *Physical Review* 51, No. 8 (15 Apr 1937): 683.

15. Wheeler, John Archibald. "Molecular Viewpoints in Nuclear Structure," *Physical Review* 52, No. 11 (01 Dec 1937), 1083 – 1106.

16. Wheeler, John A. "On the Mathematical Description of Light Nuclei by the Method of Resonating Group Structure." *Physical Review* 52, No. 11 (01 Dec 1937): 1107 – 1122.

17. Wheeler, John A. "Wave Functions for Large Arguments by the Amplitude-Phase Method." *Physical Review* 52, No. 11 (01 Dec 1937): 1123 – 1127.

18. Wheeler, John A., and Willis E. Lamb. "Influence of Atomic Electrons on Radiation and Pair Promotion." *Physical Review* 55, No. 9 (01 May 1939): 858 – 862.

19. Teller, E., and J. A. Wheeler. "On the Rotation of the Atomic Nucleus." *Physical Review* 53, No. 8 (15 May 1938): 778 – 789.

20. Bohr, Niels, and John Archibald Wheeler. "The Mechanism of Nuclear Fission." *Physical Review* 56, No. 5 (01 Sep 1939): 426 – 450.

21. Bohr, Niels, and John A. Wheeler. "The Fission of Protactinium." *Physical Review* 56, No. 10 (15 Nov 1939): 1065 – 1066.

22. Bohr, N. and J. A. Wheeler. "Mechanism of Nuclear Fission." *Journal of Applied Physics* 11, No. 1 (Jan 1940): 70 – 71.

23. Wheeler, John A., and H. H. Barschall. "The Scattering of 2.5-Mev Neutrons in Helium." *Physical Review* 58 No. 8 (15 Oct 1940): 682 – 687.

24. Wheeler, John Archibald. "The Scattering of Alpha-Particles in Helium." *Physical Review* 59, No. 1 (01 Jan 1941): 16 – 26.

25. Wheeler, John Archibald. "The Alpha-Particle Model and the Properties of the Nucleus Be^8, *Physical Review* 59, No.1 (01 Jan 1941): 27 – 36.

26. Wheeler, John A. Review of *An Introduction to the Theory of Newtonian Attraction,* by A.S. Ramsey. *Review of Scientific Instruments* 12, No. 10 (Oct 1941): 494.

27. Wheeler, John A., and Rudolf Ladenberg. "Mass of the Meson by the Method of Momentum Loss." *Physical Review* 60, No. 11 (01 Dec 1941): 754 – 761.

28. Wheeler, John Archibald, and Margaret C. Shields. "Condensed Library Guide for the Physicist." *Review of Scientific Instruments* 13, No. 4 (Apr 1942): 197 – 98.

29. Wheeler, John A., and Rupert Wildt. "The Absorption Coefficient of the Free-Free Transitions of the Negative Hydrogen Ion." *Astrophysical Journal* 95, (Mar 1942): 281 – 287.

30. Christy, R. F., and J. A. Wheeler. "Chain Reaction of Pure Fissionable Materials in Solution." U. of Chicago Metallurgical Lab. (01 Jan 1943 [Declassified 15 Dec 1955]), contract W-7401-eng-37 (A-451) CP-400.

31. Wheeler, John A. Review of *Nuclear Physics* by E. Fermi *et al*. *Review of Scientific Instruments* 14, No. 4 (Apr 1943): 98.

32. Wheeler, John A. Review of *Applied Nuclear Physics* by E. Pollard and W.L. Davidson, Jr. *Review of Scientific Instruments* 14, No. 10 (Oct 1943): 320 – 321.

33. Ibser, H. W., and Wheeler, J. A. “Theory of Characteristic Multiplication Equation with Application to Initial Conditions at Interface Between Two Multiplying Media.” U. of Chicago Metallurgical Lab. (no date [Declassified 13 Dec 1955]), C-88.

34. **Feynman, Richard Phillips**, and John Archibald Wheeler. “Interaction with the Absorber as the Mechanism of Radiation.” *Reviews of Modern Physics* 17, No. 2-3 (01 Apr 1945), 157 – 181.

35. Wheeler, John Archibald. “Problems and Prospects in Elementary Particle Research.” *Proceedings of the American Philosophical Society* 90, No. 1 (01 Jan 1946): 36 – 47.

36. Wheeler, John A. “The Future of Nuclear Power.” *Power* 90, No. 3 (Mar 1946): 92 – 94.

37. Wheeler, John Archibald. “Polyelectrons.” *Annals of the New York Academy of Sciences* 48, No. 3 (11 Oct 1946): 219 – 238.

38. Wheeler, John A., and Herbert S. Bailey, Jr. “Joseph Henry (1797—1878), Architect of Organized Science.” *American Scientist* 34, (Oct 1946): 619 – 632.

39. Wheeler, John A. “The Future of Nuclear Power.” *Mechanical Engineering* 68 (1946): 401 – 405.

40. Wheeler, John A. “Mechanism of Capture of Slow Mesons.” *Physical Review* 71, No. 5 (01 Mar 1947): 320 – 321.

41. Wheeler, John A. “Mechanism of Absorption of Negative Mesons” [Abstract]. *Physical Review* 71, No. 7 (01 April 1947): 462 – 463.

42. Wheeler, John A. “Correspondence Principle Analysis of Double-Photon Emission.” *Journal of the Optical Society of America* 37, No. 10 (01 Oct 1947): 813 – 817.

43. Wheeler, John A. “Elementary Particle Physics.” *American Scientist* 35, (1947): 117 – 193.

44. Wheeler, J. A. “Physik der Elementarteilchen.” *Die Amerikanische Rundschau* 3 (1947): 98 – 116.

45. Jaswon, M. A., and J. A. Wheeler. "Atomic Displacements in the Austenite-Martensite Transformation." *Acta Crystallographia* 1, Part 4 (Sep 1948): 216 - 224.

46. Wheeler, J. A. “How Mesons Disappear.” *AAAS Centennial Colume* edited by S.S. Negas (1949), abstract in *Science* 108 (26 Nov 1948): 588.

47. Wheeler, John A. “Niels Bohr.” in the *American Peoples Encyclopedia* Vol. 3 (1948, 1962 eds.). Chicago: The Spencer Press, 1948, 1962, 746 – 747.

48. Kane, Evan O., **T. J. Shanley**[483], and John A. Wheeler. “Influence on the Cosmic-Ray Spectrum of Five Heavenly Bodies.” *Reviews of Modern Physics* 21, No. 1 (01 Jan 1949): 51 – 71.

49. Wheeler, John A. “Some Consequences of the Electromagnetic Interaction between μ^--Mesons and Nuclei.” *Reviews of Modern Physics* 21, No. 1 (01 Jan 1949): 133 – 143.

50. Tiomno, J.[484], and John A. Wheeler. “Energy Spectrum of Electrons from Meson Decay.” *Reviews of Modern Physics* 21, No. 1 (01 Jan 1949): 144 – 152.

51. Tiomno, J., and John A. Wheeler. “Charge-Exchange Reaction of the μ-Meson with the Nucleus.” *Reviews of Modern Physics* 21, No. 1 (01 Jan 1949): 153 – 165.

52. Tiomno, J., and John A. Wheeler. “On the Spin of π- and μ-Mesons” [Abstract]. *Physical Review* 75, No. 8 (15 Apr 1949): 1306

53. Tiomno, J., and John A. Wheeler. “On the Coupling of μ-Mesons with Nucleons” [Abstract]. *Physical Review* 75, No. 8 (15 Apr 1949): 1306.

54. **Wightman, A. S**., R. E, Marshak, and J. A. Wheeler. “Absorption of Negative π-Mesons in Hydrogen” [Abstract]. *Physical Review* 75, No. 8 (15 Apr 1949): 1306.

55. Tiomno, J., and J. A. Wheeler. “Guide to Literature of Elementary Particle Physics, Including Cosmic Rays.” (w/ J. Tiomno), *Amer. Scientist* 37, No. (01 Jul 1949): 202 – 218, 342 – 348, 417 – 420, 444 – 472.

[483] John Wheeler was one of three advisors on the dissertation of Thomas James Bartlett Shanley’s 1951 dissertation.
[484] It should be noted that, despite the flurry of joint publications with John Wheeler, Jayme Tiomno’s 1951 dissertation was supervised by Eugene Wigner.

56. Wheeler, John Archibald, and **Richard Phillips Feynman**. “Classical Electrodynamics in Terms of Direct Interparticle Action.” *Reviews of Modern Physics* 21, No. 3 (01 Jul 1949), 425-433.

57. Wheeler, John A. “On the Possibility of Producing Unlimited Chains of Nuclear Reactions in a Medium Containing Uranium” [in French]. *Comptes Rendu* 229, (1949): 909 – 914.

58. Wheeler, John A. “Elementary Particle Physics.” *Science in Progress*, 6th Series, New Haven: Yale University Press, 1949, 23 – 54.

59. Wheeler, John A. “Niels Bohr.” In *Les Inventeurs Celebres: Sciences Physiques et Applications*, by Louis Leprince-Ringuet; et al. Paris: Éditions d'Art Lucien Mazenod, 1950, 298 – 301.

60. Wheeler, John A. “L’atome et L’energie Nucleaire.” In *Les Inventeurs Celebres: Sciences Physiques et Applications*, by Louis Leprince-Ringuet; et al. Paris: Éditions d'Art Lucien Mazenod, 1950, 298 – 301.

61. Wheeler, John A. “7th IUPAP Assembly, A Report from Copenhagen.” *Physics Today* 4, No. 11 (Nov 1951): 30 – 33.

62. **Hill, David Lawrence**, and John Archibald Wheeler. “Nuclear Constitution and the Interpretation of Fission Phenomena.” *Physical Review* 89, No. 5 (01 Mar 1953): 1102 – 1145.

63. **Hill, David Lawrence**, and John Archibald Wheeler. “Collective Model of the Nucleus” [Abstract]. *Physical Review* 90, No. 2 (15 Apr 1953): 366.

64. Wheeler, J. A. “Is There a Helmholtz Mixing Coefficient?” Los Alamos Scientific Laboratory (15 Sep 1953) 19 pp., contract W-7405-eng.-36. (LA-1593).

65. Wheeler, John A. “Mu Meson as Nuclear Probe Particle.” *Physical Review* 92, No. 3 (01 Nov 1953): 812 – 816.

66. Wheeler, John A. “Hendrik Anthony Kramers.” *Yearbook in American Philosophical Society*, (1953): 355 – 360.

67. Wheeler, John A. “IUPAP Assembly” *Physics Today* 7, No. 9 (Sep 1954): 28 – 29.

68. Wheeler, John A. “Discussion on the Problems of Elementary Particle Theory” (in Japanese). In *Proceedings of the Physical Society of Japan* 9 (1954): 36 – 42.

69. Wheeler, John A. “The Origin of Cosmic Rays.” In *Proceedings of the International Conference of Theoretical Physics* Kyoto and Tokyo, September 1953 by The Science Council of Japan. Tokyo: Nihon-Gakujutsu-Kaigi, 1954, 81 – 93.

70. Wheeler, John A. “Collective Model for Nuclei.” In *Proceedings of the International Conference of Theoretical Physics* Kyoto and Tokyo, September 1953 by The Science Council of Japan. Tokyo: Nihon-Gakujutsu-Kaigi, 1954, 311 – 320.

71. Wheeler, John Archibald. “Geons.” *Physical Review* 97, No. 2 (15 Jan 1955): 511 – 536.

72. Wheeler, John A. “Survey of Nuclear Models.” In *Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics*, edited by E.H. Bellamy and R.G. Moorhouse. New York: Pergamon, 1955, 38 – 45.

73. Wheeler, John A. “Nuclear Fission and Nuclear Stability.” In *Niels Bohr and The Development Of Physics Essays Dedicated To Niels Bohr On The Occasion Of His Seventieth Birthday,* edited by W. Pauli, with L. Rosenfeld and V. Weisskopf. New York: McGraw-Hill, 1955, 163 – 184.

74. Wheeler, John A. “Nuclear Models and the Collective Nucleus.” *Il Nuovo Cimento*, Ser. X, Suppl. 2 (1955): 909 – 918.

75. Wheeler, John A., and Willis E. Lamb. “Influence of Atomic Electrons on Radiation and Pair Production.” *Physical Review* 101, No. 6 (15 Mar 1956): 1836.

76. **Euwema, Robert N.** and John A. Wheeler. “First-Order Vacuum Polarizability from the Principle of Causality.” *Physical Review* 103, No. 3 (01 Aug 1956): 803 – 806.

77. Wheeler, John A. “Fission Physics and Nuclear Theory.” In *Physics: Research Reactors,* Vol. 2, *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy: held in Geneva 8 August – 20 August 1955*. New York: United Nations, 1956, 155 – 163.

78. Wheeler, John A. “Delenie Iader” [Nuclear Fission], *Atomnaia Energiia* 5, (1956): 71 – 79.

79. Wheeler, John A. “Nuclear Fission.” *Soviet Journal of Atomic Energy* 5, (1956): 743 – 751.

80. Wheeler, John A. “A Septet of Sibyls: Aids in the Search for Truth.” *American Scientist* 44, (1956): 360 – 377.

81. Wheeler, John A. “Fission.” *Physica* XXII (1956): 1103 – 1114.

82. **Euwema, Robert N**. and John A. Wheeler. “Vacuum Polarization from the Principle of Causality.” *Proceedings Of the 6th Annual Rochester Conference on High Energy Nuclear Physics*. New York: Interscience Publishers, 1956 III-42 – III-44.

83. Wheeler, John A. “Anomalies and Regularities in Fission.” In *Conference on Neutron Physics by Time-of-Flight, held at Gatlinburg, Tennessee, November 1 and 2, 1956*, by Oak Ridge National Laboratory. Oak Ridge, TN: Oak Ridge National Laboratory, 1956, 157 – 166.

84. **Lindquist, Richard W**., and John A. Wheeler. “Dynamics of a Lattice Universe by the Schwarzschild-Cell Method.” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957): 432 – 443.

85. Wheeler, John A. “Assessment of Everett's ‘Relative State’ Formulation of Quantum Theory,” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957), 463 – 465.

86. **Brill, Dieter R**., and John A. Wheeler. “Interaction of Neutrinos and Gravitational Fields,” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957): 465 – 479.

87. Power, Edmond A., and John A. Wheeler. “Thermal Geons.” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957): 480 – 495.

88. Weber, Joseph, and John A. Wheeler. “Reality of the Cylindrical Gravitational Waves of Einstein and Rosen.” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957): 509 – 515.

89. **Klauder, John**, and John A. Wheeler. “On the Question of a Neutrino Analog to Electric Charge.” *Reviews of Modern Physics* 29, No. 3 (01 Jul 1957): 516 – 517.

90. **Griffin, J. J**., and J. A. Wheeler. “Collective Motions in Nuclei by the Method of Generator Coordinates.” *Physical Review* 108, No. 2 (15 Oct 1957), 311 – 327.

91. Wheeler, John A. “No Fugitive and Cloistered Virtue.” The Presentation of the First *Atoms for Peace* Award to Niels Henrik David Bohr, October 24, 1957.

92. Regge, Tullio, and John A. Wheeler. “Stability of a Schwarzschild Singularity,” *Physical Review* 108, No. 4 (15 Nov 1957) 1063 – 1069.

93. **Misner, Charles W**., and John A. Wheeler. “Classical Physics as Geometry.” *Annals of Physics* 2, No, 6 (Dec 1957): 525 – 603.

94. Wheeler, J. A. “On the Nature of Quantum Geometrodynamics,” *Annals of Physics* 2, No, 6 (Dec 1957): 604 – 614.

95. Wheeler, John A. “Nuclear Fission.” *Magyar Fizikai Folyoirat* 6 (1957): 575 – 596.

96. Wheeler, John A. “Regularities and Anomalies in the Competition Between Neutron Emission and Fission” In *Proceedings: International Conference on the Neutron Interactions with the Nucleus. Held at Columbia University, New York, September 9 – 13, 1957*, by United States Atomic Energy Commission. Washington, DC: U.S. Department of Commerce, 1957, 146 – 152.

97. Werner, Frederick, G., and John A. Wheeler. “Superheavy Nuclei.” *Physical Review* 109, No. 1 (01 Jan 1958): 126 – 144.

98. Wheeler, John A. “Fission,” Chapter 11 in *Nuclear Physics*, part 9 in *Handbook of Physics*, edited by E.U. Condon and H. Odishaw. New York: McGraw-Hill, 1958, 177 – 200.

99. Adams, J. B., **B. K. Harrison**, **J. R. Klauder**, R. Mjolsness, **M. Wakano**, J. A. Wheeler, and R. Willey. “Some Implications of General Relativity for the Structure and Evolution of the Universe.” In *Onzieme Consel de Physique, Brussels, 1958*, *La structure et l’evolution De l’universe*, by Institute International de Physique Solvay. Brussels: Stoops, 1958, 97 – 148.

100. **Lindquist, Richard W**., and John A. Wheeler. “Erratum: Dynamics of a Lattice Universe by the Schwarzschild-Cell Method.” *Reviews of Modern Physics* 31 (01 Jul 1959): 839

101. **Ford, K. W**., **D. L. Hill**, **M. Wakano**, and J. A. Wheeler. “Quantum Effects Near a Barrier Maximum.” *Annals of Physics* 7, No. 3 (Jul 1959): 239 – 258.

102. **Ford, K.W.,** and J. A. Wheeler. "Classical Electrodynamics in Terms of Direct Interparticle Action." *Annals of Physics* 7, No. 3 (Jul 1959), 259-286.

103. **Ford, K.W.,** and J. A. Wheeler. Application of Semiclassical Scattering Analysis." *Annals of Physics* 7, No. 3 (Jul 1959): 287 – 322.

104. Wheeler, John A. "Neutrinos, Gravitation, and Geometry." In *Rendiconti della Scuola internazionale di fisica "Enrico Fermi." Corso XI*, by L. A. Radicati. Bologna: Zanichelli, 1960, 67 – 196.

105. Brandt, R., **R. Fuller**., F. G. Werner, **M. Wakano,** and J. A. Wheeler. "Effect of a Composition-Dependent Surface Tension upon the Masses and Stability of Heavy Nuclei." In *Proceedings of the International Conference on Nuclidic Masses, McMaster University, Hamilton (Canada). September 12 – 16, 1960,* edited by H. E. Duckworth. Toronto: University of Toronto Press, 1960, 94 – 123.

106. Wheeler, John A. Articles on "atomic bomb," I-648; "chain reaction, nuclear," III-6; "critical mass," III-550; "fission, nuclear," V-287 – 290. In *McGraw-Hill Encyclopedia of Science and Technology*. New York: McGraw-Hill, 1960.

107. Wheeler, John A. "Geometrodynamics and the Problem of Motion. *Reviews of Modern Physics* 33, No. 1 (01 Jan 1961): 63 – 78.

108. R. F. Baierlein, Ralph F., **David H. Sharp**[485], and J. A. Wheeler. "Three Dimensional Geometry as Carrier of Information about Time." *Physical Review* 126, No. 5 (01 Jun 1961): 1864 – 1865.

109. Wheeler, John A. "Preliminary Analysis of Instability in a Magnetic Melting Front." IDA Lob U-1902/10, IDA; JASON Summer Study, Bowdoin College, August 1961.

110. **Brill, Dieter R.,** and John A. Wheeler. "Errata: Interaction of Neutrinos and Gravitational Fields." *Reviews of Modern Physics* 33, No. 4 (01 Oct 1961): 623 – 624.

111. Wheeler, John A. "Gravitational Quanta and Waves." Vol. 3 of *Encyclopaedic Dictionary of Physics*. London and New York: Pergamon Press, 1961, 899 – 900.

[485] Although David H. Sharp earned his Ph.D. from Caltech in 1964, his 1960 Princeton Senior Thesis was supervised by John Wheeler.

112. Weber, J. and J. A. Wheeler. “Realnost Zelendrecheske Gravetazeonei vole Einsteina-Rozena” [Reality of the Cylindrical Gravitation Waves of Einstein and Rosen]. *Noveoishie Problemi Gravetazii*, edited by D. Ivanenko, Moscow, 1961, 289 – 309.

113. **Brill, D**., and J. A. Wheeler. “Vzaemodiistvii Neutrinos Gravitazeonnim Polem” [Interaction of neutrinos and gravitational fields]. *Noveoishie Problemi Gravetazii*, edited by D. Ivanenko, Moscow, 1961, 381 – 428.

114. Wheeler, John A. “Einstein’s Wiews on Space and Time: Present Status and Future Prospects.” In *Report of the 9th Conference of the Association of Princeton Graduate Alumni*. Princeton, NJ: Princeton University Press, 1961, 75 – 96.

115. Wheeler, John A. “Leadership in Engineering Science and the Shape of Our Future.” *Proceedings Of the Congreso Centenario del Colegio de Ingenieros de Venezuela*, Caracas, Venezuela, 1961.

116. Wheeler, John A. “Faraday, Dicke, and the Search for a Relation Between Gravitation and other Physical Phenomena.” *Report of the 10th Conference of the Association of Princeton Graduate Alumni*, September (Sep 1962): 75 – 96.

117. Wheeler, John Archibald. “Problems on the Frontiers between General Relativity and Differential Geometry.” *Reviews of Modern Physics* 34, No. 4 (01 Oct 1962): 873 – 892.

118. **Fuller, Robert. W**., and John A. Wheeler. “Causality and Multiply Connected Space-Time.” *Physical Review* 128, No. 2 (15 Oct 1962): 919 – 929.

119. Wheeler, John A. “Fission Then and Now.” *International Atomic Energy Agency Special Bulletin* (02 Dec 1962): 33 – 36.

120. Wheeler, John A. “Curved Empty Spacetime as the Building Material of the Physical World: An Assessment.” In *Logic, Methodology, and Philosophy of Science*, edited by E. Nagel, P. Suppes, and A. Tarski. Stanford, CA: Stanford University Press, 1962, 361 – 374.

121. Wheeler, John A. “The Place of Science in Modern Life.” *Proceedings of the 1960 Sino-American Conference on Intellectual Cooperation*. Seattle, WA: University of Washington Press, 1962, 47 – 67.

122. Wheeler, John A. "Channel Analysis of Fission." In Vol. II of *Fast Neutron Physics*, edited by J.B. Marion and J.L. Fowler. New York: John Wiley & Sons, 1962.

123. Wheeler, John A. *Geometrodynamics.* New York: Academic Press, 1962.

124. Wheeler, John A. "El Adelanto de la Ingeneria Configuracion de Nuestro Futuro." *El Farol* 200 (1962): 23 – 48.

125. Wheeler, John A. "Relativity Today." *University: A Princeton Magazine* 14 (1962): 3 – 8.

126. Bargmann, V., M. Goldberger, S. B. Treiman, J. A. Wheeler, and **A. Wightman**. "To Eugene Paul Wigner on his Sixtieth Birthday." *Reviews of Modern Physics* 34 (1962): 587 – 591.

127. Wheeler, John A. "Bohr, Niels Hendrik David." In Vol. III, *The American People's Encyclopedia*, First Edition. New York: Spencer Press, 1948, columns 746 – 747. Also in Vol. III, *The American People's Encyclopedia*. New York: Grolier Inc, 1962, columns 695 – 696.

128. Wheeler, John A. " 'No Fugitive and Cloistered Virtue' – A Tribute to Niels Bohr." *Physics Today,* 16, No. 1 (Jan 1963): 30-32.

129. Wheeler, John A. "Dr. John A. Wheeler's Views on Nuclear Testing." *Congressional Record*, House (07 Feb 1963): 1961.

130. Wheeler, John Archibald. "Niels Bohr and Nuclear Physics" [Talk delivered at Niels Bohr Memorial Session, American Physical Society Conference in Washington, DC on 22 April, 1963] *Physics Today* 16, no. 10 (Oct 1963): 36-46.

131. Tilson, Seymour, and John A. Wheeler. "The Dynamics of Spacetime." *International Science & Tech*nology (Dec 1963), 62 – 8, 70, 72 – 4.

132. Ryoyu Utiyama, Ryoyu, Satio Hayakawa, Yasuhisa Murai, Hidekazu Nariai, Toshiei Kimura, Hyôitirô Takeno, Yasutaka Tanikawa, Nobumichi Mugibayashi, Ryoyu Utiyama and John Wheeler. "Report on 'Symposium on Gravity' Held at Research Institute for Fundamental Physics in April, 1962." *Progress of Theoretical Physics Supplement* No. 25 (1963): 99-107.

133. Wheeler, John A. “The Universe in Light of General Relativity.” *The Monist* 47, No. 1 (Fall 1962): 40 – 76. Also in *Lectures in Theoretical Physics*, Vol. V, edited by W.E. Brittin and B.W. Downs, Interscience Publishers, NY (1963).

134. Wheeler, John A. Absence of a Gravitational Analog to Electrical Charge.” In *Fundamental Topics in Relativistic Fluid Mechanics and Magnetohydrodynamics*. edited by R. Wasserman and C.P. Wells, Proceedings of a Symposium held at Michigan State University, October 1962. New York: Academic Press, 1963, 1 – 20.

135. Wheeler, John A. “Mach’s Principle as Boundary Condition for Einstein’s Field Equations and as a Central Part of the Plan of General Relativity.” *Lectures in Theoretical Physics*, Vol. V, edited by W.E. Brittin and B.W. Downs. New York: Interscience Publishers, 1963. Also in *Proceedings on Theory of Gravitation, Conference in Warszawa and Jabłonna, 25 – 31 July, 1962,* edited by Leopold Infeld. Paris, Gauthier-Villars; Warszawa, P.W.N., Editions Scientifiques de Pologne, 1964. Also in *Gravitation and Relativity*, edited by H.Y. Chiu and W.F. Hoffman. New York: W.A. Benjamin, Inc., 1963.

136. Taylor, Edwin F., and John Archibald Wheeler, *Spacetime Physics* New York: W. H. Freeman, 1963.

137. Wheeler, John A. “A Few Links in the Charismatic Chain.” *Proceedings First Eastern Conference on Theoretical Physics*, October 1962, Charlottesville, VA, edited by M.E. Rose. New York: Gordon and Breach, 1963.

138. Wheeler, John A. “Science and Survival.” In *Philosophy of Science*, Vol. II, edited by B.E. Baumrin. New York: Interscience Publishers, 1963, 483 – 522.

139. Wheeler, John A. “Krumming der leeren Raum-Zeit als das Baumaterial der Physikalischen Welt: Eine Einschatzung.” *Sonderdruck aus Physikalische Blatter* 8 (1963): 354.

140. Wheeler, John A. “Absence of a Gravitational Analog to Electrical Charge.” *Relativistic Fluid Mechanics and Magnetohydrodynamics*. New York: Academic Press, 1963, pp. 1 – 20.

141. Hoyle, F., J. V. Narlikar, and J. A. Wheeler. “Electromagnetic Waves from Very Dense Stars.” *Nature* 203, No 4948 (29 Aug 1964): 914 – 916.

142. Wheeler, John A. “Xenon Footnote” in *Nuclear News* – ANS, Hinsdale, IL (Nov 1964): 55.

143. Wheeler, John A. “Gravitation as Geometry,” I and II, *Gravitation and Relativity*, edited by H.Y. Chiu and W.F. Hoffman. New York: W.A. Benjamin, 1964.

144. Wheeler, John A. The Degenerate Star: A Relativistic Catastrophe.” *Gravitation and Relativity*, edited by H.Y. Chiu and W.F. Hoffman. New York: W.A. Benjamin, 1964.

145. Wheeler, John A. “Geometrodynamics and the Issue of the Final State.” *Relativity, Groups, and Topology*, edited by C. DeWitt and B. DeWitt. New York: Gordon and Breach, 1964, 317 – 322.

146. Wheeler, John A. “Niels Bohr and Nuclear Physics.” *University: A Princeton Magazine* 20 (1964), 35 – 8.

147. Wheeler, John A. “Geometry and Relativity Today.” *Journal of Engineering Graphics* 28 (1964): 23 – 8.

148. **Thorne, Kip S**., and John A. Wheeler. “Hydrostatics and Stability of Stars in General Relativity, from an Energy Point of View.” American Physical Society Meeting, New York, January 1965.

149. Wheeler, John A. “Gravitational Collapse – to What?” [News release] National Academy of Sciences Symposium on Extraordinary Celestial Objects, April 28, 1965.

150. **Harrison, B. Kent**, **Kip S. Thorne**, **Masami Wakono**, and John Archibald Wheeler. *Gravitation Theory and Gravitational Collapse*. Chicago: University of Chicago Press, 1965.

151. **Thorne, Kip S**., and John A. Wheeler. “Hydrostatics and Stability of Stars in General Relativity, from an Energy Point of View” [Abstract]. *Bulletin of American Physical Society* 10 (1965): 15.

152. Wheeler, John A. “The Non-Locality of Force.” *Progress on Theoretical Physics Supplement Extra Number* (1965): 127 – 134.

153. Wheeler, John A. [Contributions] in *Atti del Convegno Sulla Relativita Generale; Problemi di Energiae Onde Gravitazionali*, Firenze, edited by G. Barbera, (1965) pp. 97 – 98, 115 – 17, 218 – 19, 243 – 46.

154. Wheeler, John A. “Quality of Colleagueship – Central Theme of a University.” In *On the Teaching of Science at Princeton: A Symposium* [talk given at Alumni Day luncheon, Princeton University, February 19, 1966] *Princeton Alumni Weekly* LXVI (Mar 1966): 8 – 9.

155. Wheeler, John A. “Wie Steht Es Heute mit Einsteins Idee, Alles als Geometrie zu Verstehen?” *Entstehung, Entwicklung, und Perspecktiven der Einsteinschen Gravitationstheorie*, edited by H.K. Treder. Berlin: Akademie-Verlag,1966, 14 – 25.

156. Wheeler, John A. Preface, *Precis of Special Relativity* by O. Costa de Beauregard, translated by Banesh Hoffman. New York: Academic Press,1966, v – vi.

157. Wheeler, John A. “Superdense Stars” *Annual Review of Astronomy and Astrophysics* 4 (1966): 393 – 432.

158. Wheeler, John A. “Model for Gravitational Instability.” *Perspectives in Geometry and Relativity: Essays in Honor of Vaclav Hlavaty*. Bloomington, IN: Indiana University Press, 1966, 456 – 467.

159. Schroeder, I. G., and J. A. Wheeler. “Fission.” In *Handbook of Physics*, 2nd edition, edited by E.U. Condon and High Odishaw. New York: McGraw-Hill, 1966, 9:255 – 9:271.

160. Wheeler, John A. “Mechanism of Fission.” Talk given 27 April 1967, Spring Meeting of the American Physical Society, AIP tape 5-67-3.

161. Frisch, Otto and John A. Wheeler. "The Discovery of Fission." *Physics Today* 20, no. 11 (Nov 1967): 43-52.

162. Wheeler, John A. Preface. In *Sources for History of Quantum Physics: An Inventory and Report* by T.S. Kuhn *et al*. Philadelphia: American Philosophical Society, 1967, v – ix.

163. **Harrison, B. Kent**, **Kip S. Thorne**, **Masami Wakano**, and John A. Wheeler. *Teoriya Gravitatsiii Gravitatsionneii Kollaps*, translated by Ya. B. Zel’dovich. Moskva: Isdatel’-stovo MIR, 1967, 316.

164. Wheeler, John A. “The End of Time” [Retiring address as president of the American Physical Society]. *Bulletin of the American Physical Society* 12 (1967): 3.

165. Dicke, Robert H., and John A. Wheeler. "Physics in Transition: Dialogues with Wheeler and Dicke" *Scientific Research* 2 (1967): 50 – 56.

166. Wheeler, John Archibald. "Seekers for Eternal Truth: Planck, Einstein, Bohr." In *Authentic Man Encounters God's World: Bartlett Memorial Lectures*, edited by James E. Doty. Baldwin City, KS: Baker University Press, 1967, 8 – 28.

167. Wheeler, John Archibald. "Our Changing Views of Space." In *Authentic Man Encounters God's World: Bartlett Memorial Lectures*, edited by James E. Doty. Baldwin City, KS: Baker University Press, 1967, 29 – 53.

168. Wheeler, J. A. "Three Dimensional Geometry as a Carrier of Information about Time." In *The Nature of Time*, edited by T. Gold. Ithaca, NY: Cornell University Press, 1967, 90 – 107.

169. Wheeler, J. A. [Discussion by J.A. Wheeler], in *The Nature of Time*, edited by T. Gold. Ithaca, NY: Cornell University Press, 1967, 29, 47, 60, 73 – 74, 116 – 117, 186, 233 – 240.

170. Wheeler, John A. "Einstein in Princeton." In *Einstein: The Man and His Achievement*, edited by G.J. Whitrow, London: British Broadcasting Corp., 1967, 76 - 7.

171. Wheeler, John A. "Our Universe: The Known and the Unknown." *American Scholar* 37 (1968): 248 – 274. Also in *American Scientist* 56 (Spring 1968): 1 – 20. Also in *The Physics Teacher* 7 (Jan. 1969): 24 – 34.

172. Wheeler, John Archibald. "Maria Sklodowska-Curie: Copernicus of the World of the Small." *Science* 160 No. 3832 (07 Jun 1968): 1197 – 1200. Also in *Maria Sklodowska-Curie: Centenary Lectures; Proceedings of a Symposium*, Warsaw, 17 – 20 October 1967. Vienna: IAEA, 1968, 25 – 32.

173. Wheeler, John Archibald. [Remarks on December 2, 1968 receipt of Enrico Fermi Award]. *Weekly Compilation of Presidential Documents* 4 (09 Dec 1968): 1657

174. Wheeler, J. A. “Superspace and the Nature of Quantum Geometrodynamics.” *Topics in Nonlinear Physics: Proceedings of the Physics Session, International School of Nonlinear Mathematics and Physics*. edited by N.J. Zabusky. New York: Springer-Verlag, 1968, 724. Also in *Recent Advances in Engineering Science*, Vol. III: *Proceedings of the Fourth Technical Meeting of the Society of Engineering Science*, edited by A.C. Eringen, New York: Gordon & Breach, 1968, 15 – 80.

175. Wheeler, John Archibald. *Einsteins Vision: Wie steht es heute mit Einsteins Vision, alles als Geometrie aufzufassen?* [Einstein's vision: Is Everything Geometry in Einstein's Vision as it Stands Today?] Berlin: Springer-Verlag, 1968.

176. Wheeler, John A. “Het Raadselachtige Heelal.” *Natuur en Techniek* 36e (1968): 189 – 196.

177. Wheeler, John A. “Uitdijen en Inkrimpen.” *Natuur en techniek* 36e (1968): 228 – 235.

178. Wheeler, John Archibald. “To Joseph Henry” [remarks made be JAW at the dedication of the Joseph Henry Physics Building, State University of New York at Albany, 4 October 1969.

179. DeWitt-Morette, Cecile, and John Archibald Wheeler. “Babel and Battelle.” In *Battelle Rencontres: 1967 Lectures in Mathematics and Physics*, edited by C. M. Dewitt and J.A. Wheeler. New York: W.A. Benjamin, 1969, ix - xiii.

180. Wheeler, John A. “Atomic bomb.” *McGraw-Hill Encyclopedia of Science and Technology*, Vol 1 (1969): 648.

181. Wheeler, John A. “Nuestro universo: Lo Que Sabemos y Lo Que Desconocemos.” *Fisics* I No. 3 (1969): 8 – 21.

182. Wheeler, John A. “Le Supeerespace et la Nature de la Géométrodynamique Quantique.” In *Fluldes et Champ Gravitationnel en Relativite Generale: No. 170, Colloques Internationaus*. Paris: Editions de Centre National de la Recherché Scientifique, 1969, 257 – 322.

183. Taylor, Edwin F. and John A. Wheeler. *Fizika Prostranstva-Vremeni*. Moskva: Izdatel’stvo MIR, 1969.

184. Wheeler, John A. “The Great Tradition.” In *Battelle-Columbus Laboratories News* 6 (Dec 1969). Also in *Experimental Mechanics* 10 (1970). Also in *Battelle Northwest Staff Bulletin* 66 (22 Dec 1969). Also in *Medal Day, Franklin Institute News* 7 (Win/Spr 1970).

185. Wheeler, John Archibald. “Particles and Geometry.” In *Relativity: Proceedings*, edited by Moshe Carmeli, Stuart I Fickler, and Louis Witten. New York: Plenum Press, 1970, 31 – 42.

186. Taylor, Edwin F. and John A. Wheeler. *A la Decouverte de l’Espace Tempset de la Physique Relativiste*. Paris: Dunod, Paris, 1970.

187. Wheeler, John A. *Predvedenii Einsteina*. Moskva: Izdatel’stvo MIR, 1970.

188. Wheeler, John A. “Superspace.” In *Analytic Methods in Mathematical Physics*, edited by R.P. Gilbert and R.G. Newton. New York: Gordon and Breach, 1970, 335 – 378.

189. Ruffini, Remo and John Archibald Wheeler, “Introducing the Black Hole.” *Physics Today* 24, No. 1 (Jan 1971), 30-36, 39, 41.

190. Wheeler, John Archibald. “Mechanisms for Jets.” In *Pontificiae Academiae Scientarm Scripta Varia n. 35*. Vatican City: Pontifical Academy of Sciences, 1971, 533 - 567.

191. Wheeler, John A. Foreword, *The Conceptual Foundations of Contemporary Relativity Theory* by John Cowperthwaite Graves. Cambridge, MA: The MIT Press, 1971, viiix.

192. Wheeler, John A. “Transcending the Law of Conservation of Leptons.” In *Atti del Convegno Internazionnale sul Tema: The Astrophysical Aspects of the Weak Interactions* [Cortona II Pallazzone, 10—12 Giugno 1970], Quanderno N. 157. Roma: Accademia Nationale dei Lincei, 1971, 113 - 164.

193. Ruffini, Remo, and Wheeler, John A. “Gravitational Radiation.” In *Atti del Convegno Internazionale sul Tema: The Astrophysical Aspects of the Weak Interactions* [Cortona II Pallazzone, 10—12 Giugno 1970], Quanderno N. 157. Roma: Accademia Nationale dei Lincei, 1971. 165 – 186.

194. Wheeler, John A. “From Mendeleev’s Atom to the Collapsing Star.” In *Atti del Convegno Mendeleeviano, Accademia delle Scienze di Torino,* Accademia Nazionale dei Lincei, Torino-Roma,15—21 Settembre 1969, Torino: Vincenzo Bona, 1971, 189 – 223.

195. Wheeler, John A. “Relativistic Cosmology and Space Platforms” [reprint from the *Proceedings of ESRO Colloquium, Interlaken, Switzerland, 4 September 1969*. Neuilly-sur-Seine, France: ESRO, 1971, 45 – 172.

196. Wheeler, John A. “From Mendeleev’s Atom to the Collapsing Star” [translation]. *Annals of the New York Academy of Sciences* 33 (1971): 745

197. Wheeler, John Archibald. “From Mendeleev’s Atom to the Collapsing Star.” In *A.A.A.S. Symposia on Philosophy of Science—1969*, edited by Robert S. Cohen and Raymond J. Seeger. Dordrecht: Reidel, 1974. [Reprinted from *Atti del Convegno Mendeleeviano, Accademia delle Scienze di Torino,* Accademia Nazionale dei Lincei, Torino-Roma,15 – 21 Settembre 1969, Torino: Vincenzo Bona, 1971, 189 – 223].

198. Tiomno, J., and J. A. Wheeler. “Charge-Exchange Reaction of the μ-Meson with the Nucleus.” In *Weak Interactions in Particle Physics*, Physical Society of Japan, 1972, 22 – 34.

199. **Misner, Charles W**. and John A. Wheeler. “Conservation Laws and the Boundary of a Boundary.” In *Gravitatsiya: Problemi i Perspecktivi: Pamyati Alekseya Zinovievicha Petrova Posvyashaetsya*, edited by V.P. Shelest, Kiev: Naukova Dumka, 1972, 338 – 351.

200. Taylor, Edwin F., and John A. Wheeler. “The Physics of Curved Spacetime.” in *New Trends in Physics Teaching: Tendances Nouvelles de l’enseignement de la Physique*, Vol. II [1970]. Paris: UNESCO, 1972, 45 – 64.

201. Taylor, Edwin F., and John A. Wheeler.” Fizyka Czapoprzestrzeni.” In *Panstwowe Wydawnictwo Naukowe*, Warszawa, 1972

202. Wheeler, John A. “Beyond the Black Hole.” In *Science Year: The World Book Science Annual 1973* [A Review of Science and Technology During the 1972 School Year]. Chicago: Field Enterprises Educational Corporation, 1972, 77 – 89.

203. Wheeler, John A. “Exploring the History of Nuclear Physics.” In *Proceedings of the American Institute of Physics – American Academy of Arts and Sciences Conferences on the History of Nuclear Physics, 1967 and 1969*, series edited by H.C. Wolfe, No 7 edited by C. Weiner. New York: American Institute of Physics, 1972, 9 – 249.

204. **Ball, J. A.**, J. A. Wheeler, and E. L. Firemen. “Photoabsorption and Charge Oscillation of the Thomas—Fermi Atom.” *Reviews of Modern Physics* 45, No. 3 (01 Jul 1973): 333 – 352.

205. Wheeler, John Archibald. “Zum Andenken Niels Bohrs: Ansprache zur Einweihung von Antoine Pevsners Skulptur Komposition in Dritter and Vierter Dimension am 28 September 1972.” *Physikalische Blatter* 12 (Dec 1973): 34 – 53.

206. **Misner, Charles W**., **Kip S. Thorne**, and John Archibald Wheeler. *Gravitation* New York: W. H. Freeman, 1973.

207. **Feynman, Richard Phillips**, and John Archibald Wheeler. “Interaction with the Absorber as the Mechanism of Radiation.” In *The Theory of Action-at-a-Distance in Relativistic Particle Dynamics: A Reprint Collection*, edited by Edward H. Kerner. New York: Gordon and Breach, 1973, 1 – 26.

208. Wheeler, John Archibald, and **Richard Phillips Feynman**. “Classical Electrodynamics in terms of Direct Interparticle Action.” In *The Theory of Action-at-a-Distance in Relativistic Particle Dynamics: A Reprint Collection*, edited by Edward H. Kerner. New York: Gordon and Breach, 1973, 27 – 36.

209. Wheeler, John A. “From Relativity to Mutability.” In *The Physicist’s Conception of Nature*, edited by Jagdish Mehra. Dordrecht-Holland/Boston-USA: D. Reidel Publishing Company, 1973, 202 – 247.

210. Wheeler, John A. Summary, in *Gravitational Radiation and Gravitational Collapse*, edited by Cecile DeWitt-Morrette, Reidel, Dordrecht-Holland (1974) pp. 217—23.

211. Taylor, Edwin F., and John A. Wheeler. *Terido-fizika*. Budapest: Gondolat, 1974.

212. Rees, Martin, Remo Ruffini, and John Archibald Wheeler. *Black Holes, Gravitational Waves, and Cosmology: An Introduction to Current Research*. New York: Gordon and Breach, 1974.

213. Wheeler, John A. "General Relativity, Collapse, and Singularities." In *High Energy Astrophysics and Its Relation to Elementary Particle Physics*, edited by Kenneth Brecher and Giancarlo Setti. Cambridge, MA: The MIT Press, 1974, 519 – 571.

214. Wheeler, John A. "The Black Hole." In *Astrophysics and Gravitation: Proceedings of the Sixteenth Solvay Conference on Physics*, edited by R. Debever. Brussels: Editions de l'Université de Bruxelles, 1974, 271 – 316.

215. Wheeler, John Archibald. Review of *The Physics of Time Asymmetry* by P.C.W. Davies, in *Physics Today* 28, No. 6 (Jun 1975) 49 - 50.

216. Wheeler, John Archibald. "The Universe as Home for Man." *American Scientist* 62 , No. 6 (Dec 1974): 683 – 691. Also in *The Nature of Scientific Discovery*, ed, by O. Gingerich. Washingon, DC: Smithsonian Institution Press, 1975, 261 – 296.

217. **Patton, Charles M.**[486], and John A. Wheeler. "Summary and Perspectives: Is Physics Legislated by Cosmogony?" In *Quantum Gravity*, edited by C. Isham, R. Penrose, and D. Sciama. Oxford, UK: Clarendon Press, 1975, 538 – 605.

218. Wheeler, John A. "From Magnetic Collapse to Gravitational Collapse: Levels of Understanding of Magnetism." *Annals of the New York Academy of Science* 257 (1975): 189 – 221.

219. Taylor, Edwin F., and John A. Wheeler. *Fizyka Czasoprzestrzeni* 2nd edition. Warsaw: Panstwowe Wydawnictwo Naukowe, 1975.

220. Wheeler, John Archibald. "Conference Summary: More Results Than Ever in Gravitation Physics and Relativity." In *General Relativity and Gravitation: Proceedings of the 7th International Conference (GR7)*, Tel Aviv University, June 23—28 (1974), edited by G. Shaviv and J. Rosen. New York: Wiley; Jerusalem: Israel University Press, 1975, 299 – 344.

221. Wheeler, John Archibald. Review of *The Large Scale Structure of Space-time* by S.W. Hawking and G.F.R. Ellis, *American Scientist* 63 (1975): 218.

[486] Although Charles Patton received his Ph.D. in Mathematics from SUNY, Stony Brook, John Wheeler supervised his 1972 Senior Thesis at Princeton.

222. Wheeler, John Archibald. “Semiclassical Analysis Illuminates the Connection Between Potential and Bound States and Scattering.” In *Studies in Mathematical Physics*, edited by E.H. Lieb, B. Simon[487], and **A.S. Wightman**. Princeton, NJ: Princeton University Press,1976, 351 – 422.

223. Wheeler, John Archibald. “On the Nature of the Cosmological and Black Hole Singularity.” Presented at the *Symposium on Methods of Differential Geometry in Physics and Mechanics, Warsaw 1976*. Budapest: Hungarian Academy of Sciences, Central Research Institute for Physics, 1976, 14 – 19.

224. Wheeler, John A. “Why pregeometry?” In *Actual Problems in Theoretical Physics*, Moscow, 1976.

225. Wheeler, John A. “Beyond the End of Time.” *Science et Metaphysique* 20, Archives de l’institut International des Sciences Theoreques (1976): 149 – 183.

226. Wheeler, John A. Review of *Asymptotic Structure of Space Time*, edited by F.P. Esposito & L. Witten, in *Physics Today* 30, No. 9 (Sep 1977): 56.

227. Wheeler, John Archibald. “Gravitational and Electromagnetic Wave Flux Compared and Contrasted.” *Physical Review D* 16, No. 12 (15 Dec 1977): 3384 – 3389.

228. **Misner, Charles W**., **Kip S. Thorne**, and John Archibald Wheeler. *Gravetatzeya,* edited by Dr. Igor D. Novikov & Dr. V. Braginsky, Vols. I, II, and III. Moscow: MIR, 1977.

229. Wheeler, John A. “Singularity and Unanimity” *General Relativity & Gravitation* 8 (1977): 713 -715.

230. Wheeler, John Archibald. “Man’s View of the Cosmos in America 1776—1976.” In *A Time to Hear and Answer: Essays for the Bicentennial Season*, edited by Taylor Littleton. Tuscaloosa: University of Alabama Press, 1977, 61 – 101.

231. Wheeler, John Archibald. “The Morale of Research People.” In *Discovery: Research and Scholarship at the University of Texas at Austin* 1 (1977): 2 – 3.

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[487] Barry Simon received his Ph.D. from Princeton in 1970, and is actually an intellectual grandchild of John Wheeler through Arthur S. Wightman

232. Wheeler, John A. “Include the Observer in the Wave Function?” in *Quantum Mechanics: A Half Century Later*, edited by J. Leite Lopes & M. Paty. Dordrecht-Holland: D. Reidel Publishing Company, 1977, 1 – 18.

233. Chandler, Susan, and John A. Wheeler. “Rotational Electromagnetic Preacceleration.” *Bulletin of the American Physical Society* 22 (1977): 620.

234. Wheeler, John Archibald. “Genesis and Observership.” In *Foundational Problems in the Special Sciences*, edited by R.E. Butts and K.J. Hintikka, Holland: D. Reidel Publishing Company, 1977, pp. 3 – 33.

235. Wheeler, John Archibald. “Black Hole Chemical Potential and Particle Conservation.” In *Ben Lee Memorial International Conference on Parity Non-Conservation Proceedings*, Argonne, IL (1977).

236. Wheeler, John Archibald. “A Few Specializations of the Generic Local Field in Electromagnetism and Gravitation.” In *Festschrift for I.I. Rabi*, *Transactions of the New York Academy Science* 38 (1977): 219 – 43.

237. **Patton, Charles**, and John A. Wheeler. “Is Physics Legislated by Cosmogony?” In *Encyclopaedia of Ignorance*, edited by R. Duncan and M. Weston-Smith, Oxford, UK: Pergamon Press, 1977, 19 – 35.

238. Wheeler, John Archibald. “The Art of Science.” *Postepy Fizyki* 29 (Aug 1978): 523 – 534.

239. Wheeler, John Archibald. “Magic without Magic.” Interview for *Czechoslovac Journal of Physics A* (1978).

240. Wheeler, John Archibald. “The ‘Past’ and the ‘Delayed-Choice’ Double-Slit Experiment.” In *Mathematical Foundations of Quantum Theory*, edited by A.R. Marlow. New York: Academic Press, 1978, 9 – 48.

241. Wheeler, John Archibald. “The Art of Science” [translated into Czech by Jiri Bicek]. *Ceskoslovensky Casopis pro Fyziku* 30 (1978): 364 – 374.

242. Wheeler, John Archibald. “Karl Herzfeld” [Obituary]. *Physics Today* 32, no.1 (Jan 1979): 99.

243. Wheeler, John Archibald. “Einstein, Things and Thinkers.” *Physics Today* 32, No. 3 (Mar 1979): 144.

244. Wheeler, John Archibald. “Free-form Poem.” In *The Washington Post* (Sun, 11 Mar 1979), Sec C. p. 4.

245. Wheeler, John Archibald. “The Outsider.” *Newsweek* (12 Mar 1979): 67.

246. Wheeler, John Archibald. Excerpt from Houston AAAS speech, in *The Skeptical Inquirer III* (Spr 1979).

247. Wheeler, John A. “Collapse and Quantum as Lock and Key.” *Bulletin of the American Physical Society* (Apr 1979): 24.

248. Wheeler, John Archibald and Martin Gardner. “Quantum Theory and Quack Theory.” *The New York Review of Books* 26, No. 8 (17 May 1979).

249. Wheeler, John Archibald. “A Decade of Permissiveness” [letter to William Carey, American Association for the Advancement of Science]. *The New York Review of Books* 26, No. 8 (17 May 79).

250. Wheeler, John Archibald. Dedication speech for Einstein Memorial, National Academy of Sciences, *Letter to Members* 9 no. 3 (Jun 1979): 1 – 3.

251. Wheeler, John Archibald, and J. B. Rhine. “Parapsychology – A Correction.” *Science* 205, no. 4402 (13 Jul 1979): 144.

252. Wheeler, John Archibald. “Black Hole as the Gate of Time.” In *The Kagaku Asahi*, (Aug 1979): 39 – 44.

253. Wheeler, John Archibald. “Einstein und Was Er Wolte” *Physikalische Blatter* (Sep 1979): 385 – 397.

254. Wheeler, John Archibald. “From the Big Bang to the Big Crunch” *Cosmic Search* 1 (Fall 1979): 2 – 8.

255. Wheeler, John Archibald. “Albert Einstein y Su Esperanza.” *Naturaleza 10*, Mexico City, (Oct 1979).

256. Wheeler, John Archibald. “Understanding How the Universe Came into Being – Has a Key to the Paradox/Lock Been Found?” *Science Digest* (Oct 1979): 38 – 45.

257. “Free-Form Poem.” *Valuation* 25 (Nov 1979): 13.

258. Wheeler, John A. “Einstein and Other Seekers of the Larger View.” *Science and Public Policy* 6 (Dec 1979): 396-404.

259. Wheeler, John Archibald. *Frontiers of Time*. Amsterdam: North-Holland Publishing Co., 1979.

260. Wheeler, John Archibald. “Frontiers of Time.” In *Rendiconti della Scuola Internazionale di Fisica `Enrico Fermi’*, edited by N. Toraldo di Francia & Bas van Fraassen. Amsterdam: North-Holland Publishing Co., 1979, 213 – 322.

261. Wheeler, John Archibald. “Some Men and Moments in the History of Nuclear Physics: The Interplay of Colleagues and Motivations.” In *Nuclear Physics in Retrospect: Proceedings of a Symposium on the 1930’s.* Edited by Roger H. Stuewer. Minneapolis, MN: University of Minnesota Press, 1979, 217 – 284.

262. Wheeler, John A. “Black Hole: An Imaginary Conversation with Albert Einstein.” In *Albert Einstein: His Influence on Physics, Philosophy, and Politics,* edited by Peter C. Aichelburg and Roman U. Sexl. Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979.

263. Wheeler, John Archibald. “Mercer Street and other Memories.” In *Albert Einstein: His Influence on Physics, Philosophy, and Politics,* edited by Peter C. Aichelburg and Roman U. Sexl. Braunschweig, Germany: Friedr. Vieweg & Sohn, 1979.

264. Wheeler, John Archibald. “Mercer Street and other Memories.” In *Albert Einstein’s Theory of General Relativity*, edited by Gerald Tauber. New York: Crown Publishers, NY, 1979, 182 – 195.

265. Wheeler, John Archibald. “Memoir.” In *Einstein: A Centenary Volume*, edited by A.P. French. London: Heineman for the International Commission on Physics Education, 1979, 21 – 22.

266. Wheeler, John Archibald. “Mercer Street and Other Memories” [translated into Czech by Jiri Bicek]. *Ceskoslovensky Casopis pro Fyziku* 29 (1979): 260 – 269.

267. Wheeler, John A. “The Art of Science” [translated into Czech by Jiri Bicek]. *Postepy Fizyki* 30 (1979): 467 – 475.

268. Wheeler, John A. “Einstein at Princeton.” *Shizen* 34 (1979): 29 – 39.

269. Wheeler, John Archibald. “Relativity – Sixty years On.” BBC Publications,1979.

270. Wheeler, John Archibald. “Conversations.” In *A Question of Physics: Conversations in Physics and Biology*, edited by P. Buckley and F.D. Peat. Ontario, Canada: University of Toronto Press, 1979, 51 – 61.

271. **Isenberg, James**[488], and John Archibald Wheeler.” “Inertia Here is Fixed by Mass-Energy There in Every W Model Universe.” In *Relativity, Quanta, and Cosmology in the Development of the Scientific Thought of Albert Einstein*, edited by M. Pantaleo and F. deFinis. New York: Johnson Reprint Corporation, 1979, 267 – 293.

272. Wheeler, John Archibald. “The Quantum and the Universe.” In *Relativity, Quanta, and Cosmology in the Development of the Scientific Thought of Albert Einstein*, Vol. II, edited by M. Pantaleo and F. defines. New York: Johnson Reprint Corporation, 1979, 807 – 825.

273. **Isenberg, James**, and John Archibald Wheeler. “L’inerzia In Un Punto E Fissata Dalla Distribuzione Di Massa: Energia Lontano in Ogni Universo A Modello W (w/ James Isenberg). In *Astrofisica e Cosmologia Gravitazione Quanti e Relativita*, edited by M. Pantaleo and F. deFinis. Firenze: Giunti Barbera, 1979, 1099 - 1136.

274. Wheeler, John Archibald. “I Quanti E L’Universo.“ In *Astrofisica e Cosmologia Gravitazione Quanti e Relativita*, edited by M. Pantaleo and F. deFinis. Firenze: Giunti Barbera, 1979, 1137 – 1163.

275. Wheeler, John Archibald. “Einstein und Was Er Wollte.” In *Einstein-Centenarium* 1979, edited by H.J. Treder. Berlin: Akademie-Verlag, 1979.

276. Wheeler, John Archibald. “Einstein und Was Er Wollte.” In *Max-Planck-Gesellschaft, Berichte, und Mitteilungen*. Munchen: der General verwaltung der Max-Planck-Gessellschaft, 1979, 57 – 69.

277. Wheeler, John Archibald. “Klassicheskaya Fizika Kak Geometriya.” In *Albert Einstein: Teoriya Gravitatzi*, edited by Kvornik Statei. Moscow: Mir, 1979, 542 – 557.

[488] John Wheeler supervised James Isenberg’s 1973 Senior Thesis at Princeton. Isenberg is also an intellectual ‘grandchild’ of Wheeler through Charles Misner at U. Maryland.

278. Bohr, Niels, and John A. Wheeler. “The Mechanism of Nuclear Fission” [reprint of 1939 article of same title], *40 JahreKernspaltung: Ein Einfuhrung in Dir Originalliterature*. Darmstadt: Wissenschaftliche Buchgesellschaft, 1979, 141 – 190.

279. Wheeler, John A. “Pregeometry: Motivations and Prospects.” In *Quantum Theory and Gravitation: Proceedings of a Symposium held at Loyola University, New Orleans, May 23 – 26, 1979*, edited by A. R. Marlow. New York: Academic Press, 1980, 1 – 11.

280. Wheeler, John Archibald. “Albert Einstein March 14, 1879 – April 18, 1955.” In National Academy of Sciences. *Biographical Memoirs,* Vol. 51. Washington, DC: National Academy of Sciences, 1980.

281. Wheeler, John Archibald. “Albert Einstein Remembered.” In *The Americana Annual* (1980): 28 – 34.

282. Wheeler, John Archibald. “The Beam and Stay of the Taub Universe.” In *Essays in General Relativity*, edited by Frank J. Tipler. New York: Academic Press, 1980, 59 – 70.

283. Wheeler, John Archibald. “Beyond the Black Hole.” In *Some Strangeness in the Proportion*, edited by H. Woolf. Reading, MA: Addison-Wesley, 1980, 341 – 375.

284. Wheeler, John Archibald. “Law Without Law.” In *Structure in Science and Art*, edited by P. Medawar and J. Shelley. Amsterdam-Oxford-Princeton: Excerpta Medica, 1980, 132 – 154.

285. Wheeler, John Archibald. “Einstein: His Strength and His Struggle.” Working Paper. Twentieth Selig Brodetsky Memorial Lecture, University of Leeds, 8 May 1979. Leeds, UK: Leeds University Press, 1980.

286. Wheeler, John Archibald. “Einstein and Other Seekers of the Larger View.” in *Einstein, The First Hundred Years*, edited by M. Goldsmith. A. Mackay, and J. Woudhuysen. Oxford, UK: Pergamon Press, 1980, 59 – 98.

287. Wheeler, John Archibald. “Physics as Geometry.” *Epistemologica* III, 59—98 (1980): 59 – 98.

288. Wheeler, John Archibald. “Delayed-Choice Experiments and the Bohr-Einstein Dialog.” In *The American Philosophical Society and the Royal Society: Papers Read at a Meeting, June 5, 1980,* edited by American Philosophical Society; Royal Society (Great Britain). Philadelphia: American Philosophical Society, 1980, 9 – 40.

289. Wheeler, John Archibald. “The Lesson of the Black Hole.” *Proceedings of the American Philosophical Society* 125 No. 1 (16 Feb 1981): 25 – 37.

290. Wheeler, John Archibald. “Not Consciousness but the Distinction Between the Probe and the Probed as Central to the Elemental Quantum Act of Observation.” In *The Role of Consciousness in the Physical World*, edited by R.G. Jahn: Boulder: Westview Press, 1981, 87 – 111.

291. Taylor, Edwin F., and John Archibald Wheeler. *Spacetime Physics*. Kyoto: Modern Mathematics Association, 1981.

292. Kirkpatrick, R. C., and J. A. Wheeler. “The Physics of D.T. Ignition in Small Fusion Targets.” *Nuclear Fusion* 21 (1981): 389 - 401.

293. Wheeler, John Archibald. [Conversation]. *Death and the Creative life: Conversations with Prominent Artists and Scientists*, by Lisl Marburg Goodman. New York: Springer Publishing Co., 1981, 76 – 83.

294. Wheeler, John Archibald. “Beyond the Black Hole.” *Nature Journal*. Shanghai: Science and Technology Publishing House, 1981, 674 – 681.

295. Wheeler, John Archibald. “The Elementary Quantum Act as Higgledy-Piggledy Building Mechanism.” In *Quantum Theory and the Structures of Time and Space, Volume 4: Papers Presented at a Conference held in Tutzing, July 1980,* by L Castell; Carl Friedrich Weizsäcker. Münich: Carl Hanser, Verlag, 1981, 27 – 30.

296. Wheeler, John A. “The Black Hole and New Physics.” *Discovery*, The University of Texas, Austin (Win 1982).

297. Wheeler, John Archibald. “The Computer and the Universe.” *International Journal of Theoretical Physics* 21, No. 6-7, Plenum (Jun 1982): 557 – 572.

298. Wheeler, John A. *Physics and Austerity*. Anuhui, China: Anhui Science and Technology Publications, (Aug 1982).

299. Wheeler, John Archibald. “Hideki Yukawa as Uniquely Ecumenical.” *Journal of the Physical Society Of Japan* 37 (1982): 324 – 325.

300. Wheeler, John A. “Bohr, Einstein, and the Strange Lesson of the Quantum.” *Mind in Nature*, *Nobel Conference XVII, Gustavus Adolphus College, St. Peter, MN*, edited by Richard Q. Elvee. New York: Harper and Row, 1982, 1 – 30.

301. Wheeler, John Archibald. “Particles and Geometry.” In *Unified Theories of Elementary Particles*, edited by P. Breitenlohner and H.P. Durr Berlin-Heidelberg-New York: Springer-Verlag, 1982, 189 – 217.

302. Wheeler, John Archibald. “Einstein and Other Seekers of the Wider View.” *Indianapolis Journal of Mathematics and Physics* 1 - 2, (1982 – 1983): 1 – 25.

303. Wheeler, John Archibald. “The Geometrostatic Lattice Cell.” *Foundations of Physics* 13 (Jan 1983): 161 – 173.

304. Wheeler, John Archibald. “On Recognizing Law Without Law.” *American Journal of Physics*. 51 (May 1983): 398 – 404.

305. Armour, Rolin S. Jr., and John A. Wheeler. “Physicist’s Version of Traveling Salesman Problem: Statistical Analysis.” *American Journal of Physics*. 51 (May 1983): 405 – 406.

306. Wheeler, John Archibald. “Jenseits aller Zeitlichkeit.” *Die Zeit* [Ital.], edited by Anton Peisl und Armin Mohler. *Schrifter der Carl Friedrich von Seimens-Stiftung Band 6*, R. Oldenbourg. Munchen: Verlag, 1983, 17 – 34.

307. Wheeler, John A. Review of *The Fractal Geometry of Nature* by B. Mandelbrot, *American Journal of Phys*ics 51, No. 3 (1983): 286 – 287.

308. Wheeler, John Archibald. “Einstein’s Second Century.” In *Proceedings of the Ninth International Conference on General Relativity and Gravitation, Jena, 14-16 July 1980 / Under the Auspices of International Society for General Relativity and Gravitation, International Union of Pure and Applied Physics [and] Friedrich Schiller University, Jena*, edited by E. Schmutzer. New York : Cambridge University Press, 1983, 23 – 38.

309. Wheeler, John Archibald. “Introduction to General Relativity.” In *Quantum Optics, Experimental Gravitation, and Measurement Theory*, edited by P. Meystre and M. Scully. New York: Plenum Press, 1983, 9 – 41.

310. Wheeler, John Archibald. “Elementary Quantum Phenomenon as Building Unit.” In *Quantum Optics, Experimental Gravitation, and Measurement Theory*, edited by P. Meystre and M. Scully, Plenum Press, New York-London (1983) pp. 141—3.

311. Wheeler, John Archibald. “Beyond the End of Time.” in *Krisis*, edited by I. Marculescu. Paris: Klinckscieck, 1983, 67 – 75.

312. Wheeler, John Archibald, and Wojciech Hubert Zurek. *Quantum Theory and Measurement.* Princeton, NJ: Princeton University Press, 1983

313. Bohr, Niels and Wheeler, John Archibald. “The Mechanism of Nuclear Fission” (reprint of 1939 article). In *Energy in Atomic Physics 1925-1960*, edited by R.B. Lindsay. Stroudsburg: Hutchinson Ross, 1983, 226 – 250.

314. Wheeler, John Archibald. “The Universe as Home for Man” [exerpt from 1975 article in *The Nature of Scientific Discovery*. Washington, DC: Smithsonian Institution, 1975], *The Dynamic Universe: An Introduction to Astronomy*, edited by Theodore P. Snow. St. Paul, MN: West Publishing Co., 1983, 108 – 109.

315. Wheeler, J. Craig, and John A. Wheeler, “Detection of Gravitational Collapse.” In *Science Underground: (Los Alamos, 1982)*, edited by M. Nieto, W. Haxton, C. Hoffman, E. Kolb, V. Sandberg, and J. Toevs. AIP Conference Proceedings, No. 96. New York: American Institute of Physics, 1983, 214 – 224.

316. Wheeler, John A. “Como si Controlla un Reattore.” *Il Tempo*, Rome (10 Dec 1984): 19.

317. Wheeler, John Archibald. “Quantum Gravity: the Question of Measurement.” In *Quantum Theory of Gravity: Essays in Honor of the 60th Birthday of Bryce S. DeWitt,* edited by Steven M. Christensen. Bristol: A. Hilger, 1984, 224 – 233.

318. Wheeler, John Archibald. “Delayed-Choice Experiments and Bohr’s Elementary Quantum Phenomenon.” In *Proceedings of the International Symposium Foundations of Quantum Mechanics in the Light of New Technology : Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo, Japan, August 29-31, 1983,* edited by S Kamefuchi; Nihon Butsuri Gakkai.; et al. Tokyo, Japan: Physical Society of Japan, 1984.

319. Wheeler, John Archibald. “Berry’s Angle and A-B Effect” [Abstract]. In *Proceedings of the International Symposium Foundations of Quantum Mechanics in the Light of New Technology : Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo, Japan, August 29-31, 1983,* edited by S Kamefuchi; Nihon Butsuri Gakkai.; et al. Tokyo, Japan: Physical Society of Japan, 1984.

320. Wheeler, John Archibald. Die Experimente der Verzogerten Entscheidung und der Dialog zwischen Bohr und Einstein.“ In *Modern Naturphilosophie*, edited by B. Kanitscheider. Würzburg: Konigschausen and Neumann, 1984, 203 – 222.

321. Ruffini, Remo, and John Archibald Wheeler. “Introducing the Black Hole.” In *Astrophysics Today*, edited by A.G.W. Cameron. New York: American Institute of Physics, 1984, 178 – 85.

322. Wheeler, John Archibald. “Highlights of the Conference.” *In General Relativity and Gravitation, invited Papers and Discussion Reports of the 10th International Conference on General Relativity and Gravitation, Padua, Italy, 3 – 8 July 1983*, edited by B. Bertotti, F. de Felice, and A. Pascolini. Dordrecht/Boston/Lancaster: D. Reidel Publishing Co., 1984, 501 – 509.

323. Wheeler, John A. “Saddle Points and Nuclear Fission.” In *Algebraic and Differential Topology, Global Differential Geometry*, edited by G. Rassias. Leipzig: Teubner Text zur Mathematik, Band 70, Teubner, 1984, 306 – 317.

324. Wheeler, John Archibald. “Bits Quanta, Meaning.” *Theoretical Physics Meeting*, Commemorative Volume on the Occasion of Eduardo Caianiello’s 60th Birthday, edited by A. Giovanni, M. Marinaro, F. Mancini, A. Rimini. Naples: Edizioni Scientifiche Italiane, 1984, 121 – 134.

325. Wheeler, John Archibald. “Niels Bohr, the man.” *Physics Today* 38, no. 10 (Oct 1985): 66-72.

326. Wheeler, John Archibald. “Bohr’s Phenomenon and Law Without Law.” In *Chaotic Behavior in Quantum Systems: Theory and Applications; [Proceedings of a NATO Advanced Research Workshop on Quantum Chaos: Chaotic Behavior in Quantum Systems, Theory and Applications, held June 20 - 25, 1983, in Como, Italy*. edited by Giulio Casati. New York : Plenum Press, 1985, 363 – 378.

327. John A. Wheeler. Forward, *Numerical Astrophysics*, edited by J. Centrella, J. LeBlanc, and R. Bowers. Boston: Janes and Bartlett, 1985, iii.

328. Frisch, Otto, and John A. Wheeler. “The Discovery of Fission.” In *History of Physics*, edited by Spencer R. Weart and Melba Phillips. New York: American Institute of Physics, 1985, 272 – 281.

329. Wheeler, John Archibald. “Ideas.” In *Proceedings of the Philosophical Society of Texas Meeting XLVIII, 7 – 8 December 1984*. Austin: Philosophical Society of Texas, 1985, 11 – 18.

330. Wheeler, John A. “Franck-Condon Effect and Squeezed-State Physics as Double-Source Interference Phenomena.” *Letters in Mathematical Physics* 10 (1985): 201 – 206.

331. Wheeler, John Archibald. “Gravitational Collapse of a Gravitational Wave via Geon Transition State.” In *A Random Walk in Relativity and Cosmology, Essays in Honour of P.C. Avidya and A.K. Raychaudhuri*, edited by N. Dadhich, J. Krishna Rao, J.V. Narlikar, and C.V. Vishveshwara. New Delhi: Wiley Eastern Ltd., 1985, 222 – 228.

332. Wheeler, John Archibald. “Niels Bohr, the man.” [Japanese translation of *Physics Today* article] *Parity* 1, No. 4 (1985): 16 – 25.

333. Wheeler, John Archibald. “The Universe as Home for Man” [excerpt]. In *The Dynamic Universe*, 2nd edition, edited by Theodore P. Snow. St. Paul, MN: West Publishing Co., 1985, 124 – 125.

334. Qadir, Asghar, and John A. Wheeler. “York’s Cosmic Time versus Proper Time as Relevant to Changes in the Dimensionless Constants, K-meson Decay, and the Unity of Black Hole and Big Crunch.” In *From SU(3) to Gravity*, edited by E. Gotsman and G. Tauber. Cambridge, UK: Cambridge University Press, 1985, 383 – 394.

335. Wheeler, John Archibald. “Physics in Copenhagen in 1934 and 1935.” In *Niels Bohr: A Centenary Volume*, edited by A.P. French and P.J. Kennedy Cambridge, MA: Harvard University Press, 1985, 221 – 226.

336. Bohr, Niels and Wheeler, John Archibald. “The Mechanism of Nuclear Fission” [reprint of 1939 article]. In *Niels Bohr: A Centenary Volume*, edited by A.P. French and P.J. Kennedy. Cambridge, MA: Harvard University Press, 1985, 221 – 226.

337. Wheeler, John Archibald. “Delayed-Choice Experiments and the Bohr-Einstein Dialog.” In *Niels Bohr: A Profile*, edited by A.N. Mitra, L.S. Kothari, V. Singh, and S.K. Trehan. New Delhi: Indian National Science Academy, 1985, 139 – 168.

338. Bohr, Niels and Wheeler, John Archibald. “The Mechanism of Nuclear Fission” [reprint of 1939 article]. In *Niels Bohr: A Profile*, edited by A.N. Mitra, L.S. Kothari, V. Singh, and S.K. Trehan. New Delhi: Indian National Science Academy, 1985, 79 –103.

339. **Miller, Warner A**., and John A. Wheeler. “4 Geodesy.” *Il Nuovo Cimento* 8 (1985): 418 – 434.

340. Wheeler, John Archibald. “Herman Weyl and the Unity of Knowledge.” *American Scientist* 74, No. 4 (Jul-Aug 1986): 366 – 375.

341. Wheeler, John Archibald. “How Come the Quantum?” In *New Techniques and Ideas in Quantum Measurement Theory*, edited by D. Greenberger, *Annals of the New York Academy of Science* 480 (Dec 1986): 304 – 316.

342. Wheeler, John A. “Foreword,” to *The Anthropic Cosmological Principle,* by John D. Barrow and Frank J. Tipler. New York: Oxford University Press, 1986.

343. Wheeler, John Archibald. “Physics as Meaning Circuit: Three Problems.” In *Frontiers of Nonequilibrium Statistical Physics, Proceedings of a NATO Advanced Study Institute on Frontiers of Non-equilibrium Statistical Physics, 3—17 June 1984, Santa Fe, NM*, edited by G.T. Moor and M.O. Scully. New York: Plenum Press, 1986, 25 – 32.

344. Wheeler, John Archibald. “Toward the Whole Human.” In *The Inauguration of George Rupp, Rice University*, 25 October 1985. Houston, TX: Rice University Press, 1986, 6 – 7.

345. **Kheyfets, Arkady**, and John A. Wheeler. “Boundary of a Boundary Principle and Geometric Structure of Field Theories.” *International Journal of Theoretical Physics* 25, No. 6 (1986): 573 – 580.

346. Wheeler, John Archibald. “Niels Bohr: The Man and his Legacy.” In *The Lesson of Quantum Theory*, edited by J. deBoer, E. Dal, and O. Ulfbeck. Amsterdam: North-Holland for the Royal Danish Academy of Sciences and Letters; New York: Elsevier Science Pub. Co., 1986, 355 – 367.

347. Wheeler, John Archibald. “On the Shoulders of Giants.” In *The Educational Forum*, A Publication of Kappa Delta Pi, (1986): 11—14

348. Wheeler, John Archibald. “Arms and Technology as Factors in the Maintenance of Peace. In *The Future of U.S.-U.S.S.R. Relations: Lessons from Forty Years without World War, Proceedings of a Symposium Sponsored by the Tom Slick Memorial Trust, 3 – 4 April 1986, University of Texas, Austin*, edited by R. German. Austin, TX: Lyndon B. Johnson School of Public Affairs: Distribution through Texas Monthly Press, 1986, 49 – 52.

349. Wheeler, John Archibald. “John Wheeler: Role of the Observer in Quantum Mechanics.” In *The Ghost in the Atom: A Discussion of the Mysteries of Quantum Physics*, edited by P.C.W. Davies and J.R. Brown. Cambridge, UK: Cambridge University Press, 1986, pp. 58—69.

350. Schleich, Wolfgang and John A. Wheeler. “Oscillations in Photon Distribution of Squeezed States.” *Journal of the Optical Society of America B* II, 4 (Oct 1987): 1715 – 1722.

351. Schleich, Wolfgang and John A. Wheeler. “Oscillations in Photon Distribution of Squeezed States and Interference in Phase Space.” *Nature* 326, No. 6113 (1987): 574 – 577. Also in *Selected Papers on Photon Statistics and Coherence in Nonlinear Optics*, a publication of SPIE – The International Society for Optical Engineering, MS 39 (1987): 386 – 393. edited by Jan Perena, Bellingham, WA.

352. Schleich, Wolfgang and John A. Wheeler. “Interference in Phase Space.” In the *Proceedings of the First International Conference on the Physics of Phase Space/* edited by S. Kim and W.W. Zachary. New York: Springer, 1987, 1177 – 1186.

353. Wheeler, John Archibald. Foreward to *Hermann Weyl – The Continuum: A Critical Examination of the Foundation of Analysis*, translated by S. Pollard and T. Bole. Kirksville, MO: Thomas Jefferson University Press, 1987, ix—xiii.

354. Wheeler, John Archibald. “Superspace and the Nature of Quantum Geometrodynamics.” In *Quantum Cosmology* ed L. Z. Fang and R. Ruffini. Teaneck, NJ: World Scientific Publishing, 1987, 27 – 92.

355. Schliech, W., D. F. Walls, and J. A. Wheeler. “Area of Overlap and Interference in Phase Space Versus Wigner Pseudo-Probabilities.” *Physical Review A* 38 No. 3 (01 Aug 1988): 1177 – 1186.

356. Schleich, W., H Walther, and J. A. Wheeler. “Area in Phase Space as Determiner of Transition Probability: Bohr-Sommerfeld Bands, Wigner Ripples, Fresnel Zones” [reprinted from] *Foundations of Physics* 18, No. 10 (1988).

357. Wheeler, John Archibald. “World as System Self-Synthesized by Quantum Networking.” IBM *Journal of Research and Development* 32, No. 1 (1988): 4 – 15.

358. Wheeler, John Archibald. “World as System Self-Synthesized by Quantum Networking.” In *Probability in the Sciences*, edited by Evandro Agazzi. Dordrecht, The Netherlands: Kluwer Academic Publishers, 1988, 103 – 130.

359. Wheeler, John Archibald. “The 2-Photon Elementary Quantum Phenomenon and Spacetime Structure.” In *Microphysical Reality and Quantum Formalism: Proceedings of the Conference 'Microphysical Reality and Quantum Formalism', Urbino, Italy, September 25th - October 3rd, 1985*, edited by Alwyn Van der Merwe. Dordrecht: Kluwer, 1988, 215 – 218.

360. Wheeler, John Archibald. “Geometrodynamic Steering Principle Reveals the Determiners of Inertia.” *International Journal of Modern Physics A* 3, No. 10 (1988): 2207 – 2248 (1988), World Scientific, Singapore. Also in the *Proceedings of the 4th Seminar on Quantum Gravity, 25—29 May, 1987, Moscow, USSR*, edited by M.A. Markov, V.A. Berezin, and V.P. Frolov. Singapore: World Scientific, 1988, 21 – 93.

361. Wheeler, John Archibald. “Nonosecond Matter.” In *Energy in Physics, War and Peace: A Festschrift Celebrating Edward Teller’s 80th Birthday*, edited by H. Mark and L. Wood. Dordrecht, The Netherlands: Kluwer Academic Publishers, 1988, 87 – 100.

362. **Kheyfets, Arkady**, **Warner A. Miller**, and John A. Wheeler. “Null-Strut Calculus: The First Test.” *Physical Review Letters* 61, No. 18 (31 Oct 1988): 2042 – 2045.

363. Wheeler, John Archibald. “Bibliography of Selected Wheeler Contributions to Physics.” In Kip S. Thorne and Wojciech H. Zurek, “A Few Highlights of his Contributions to Physics.” *Between Quantum and Cosmos*, edited by W.H. Zurek, A.V. Merwe, W.A. Miller. Princeton, NJ: Princeton University Press, 1988, 2 – 14.

364. Wheeler, John Archibad. *Einstein: Gestern Heute, Morgen*,” Manuscript of lecture given on receipt of the Albert Einstein Prize, Bern, Switzerland, 6 June 1988. Deposited in the archives of The Albert Einstein Gesellschaft of Bern, 1988, 1 – 6.

365. Wheeler, John Archibad. “Hermann Weyl and the Unity of Knowledge.” In *Exact Sciences and their Philosophical Foundations – Exakte Wissenschaften und ihre Philosophische Grundlegung: Vortrage des Internationalen Hermann-Weyl-Kongresses, Kiel 1985*, edited by W. Deppert, K. Hubner, A. Oberschelp, and V. Weidermann. Frankfurt am Main: Peter Lang, 1988, 469 – 504.

366. Qadir, Asghar, and John A. Wheeler. “Late Stages of Crunch.” In *Proceedings of the International Symposium on Spacetime Symmetries in Commemoration of the 50th Anniversary of Eugene Paul Wigner's Fundamental Paper on the Inhomogeneous Lorentz Group: College Park, Maryland, USA, 24-28 May, 1988*, edited by Y. S. Kim; W. W. Zachary; Eugene P Wigner. Amsterdam: North-Holland, 1989, 345 – 348.

367. Wheeler, John Archibald. “The Young Feynman.” *Physics Today* 42, no.2 (Feb 1989): 24-28 ;and for the the Feynman Memorial Session of the American Association for the Advancement of Science, The American Association of Physics Teachers and the American Physics Society, San Francisco (February 1988).

368. Wheeler, John Archibald. “Aniversario del nacimiento de Einstein”, in *El Porvenir*, 14 March 1989, [translation of talk given in March 1979 at the 100th birthday celebration of Albert Einstein.]

369. “Potremo mai arrivare a comprendere l’esistenza?”, *Nuova Civilta delle Macchine: Rivista Trimestrale di Analisie Critica*, *Anno VIII* 4 (1990): 32 – 47.

370. Wheeler, John Archibald. *A Journey into Gravity and Spacetime*. New York: Scientific American Library, 1990.

371. Wheeler, John Archibald. *Gravitation und Raumzeit* [German translation of *Journey into Gravity and Spacetime*]. Heidelberg: Spektrum de Wissenschaft, 1990.

372. Wheeler, John Archibald. "Information, Physics, Quantum: The Search for Links."In *Complexity, Entropy, and the Physics of Information: The Proceedings of the 1988 Workshop on "Complexity, Entropy, and the Physics of Information, held 29 May - 10 June, 1989 in Santa Fe, New Mexico*, edited by Wojciech H. Zurek. Redwood City, CA: Addison-Wesley, The Advanced Book Program, 1990, 3 – 28. Also appeared under same title in the *Proceedings of the 3rd International Symposium Foundations of Quantum Mechanics in the Light of New Technology*, edited by S. Kobayashi *et al*. Tokyo: The Physical Society of Japan, 1990, 354 – 368.

373. Wheeler, John Archibald. "Élie Cartan, Albert Einstein, and Almost Everything from Almost Nothing." *In General Conference Publications of Gakushuin University, Tokyo*, No. 8 (1990): 39 – 58.

374. Wheeler, John Archibald. "Necklace Orbit in Atom and Black Holes." In *Erkenntnis und Engagement: Festschrift für Hans-Peter Durr zum 60 Geburtsag*, edited by H. Saler, Max-Planck-Institut für Physik und Astrophysik, 1990, 295 – 297.

375. Wheeler, John Archibald. "Wie Kommt es zum Quantum?" *Philosophia Naturalis* 2 (1990): 1 – 19.

376. Wheeler, John Archibald. "It from Bit" in *Serge Korff and Recent Thinking About the Nature of the Physical World*, adapted from a paper presented at the First Andrei Sakharov International Physics Conference, Moscow, USSR (May1991).

377. Wheeler, John Archibald. "The Real Discovery of America: Mexico November 8, 1519", lecture given for the first *Anshen Transdisciplinary Lectureships in Art, Science, and Philosophy of Culture*, The Frick Collection, NY, 7 November 1991.

378. Wheeler, John Archibald. "The Black Hole: Past, Present, and Future", a Tanner Academic Lecture, in *Encyclia* [the Journal of the Utah Academy of Sciences, Arts, and Letters] 67 (1991): 29 – 50.

379. Wheeler, John Archibald. “Sakharov: Man of Humility, Understanding, and Leadership.” In *Andrei Sakharov*, *Facts of Life*, edited by B.L. Altschuler *et al*. Cedex, France: Éditions Frontières, Gif-sur-Yvette, 1991, 647 – 649.

380. Wheeler, John Archibald. “Sakharov Revisited: It from Bit.” In *Proceedings of the First International A.D. Sakharov Memorial Conference on Physics, Moscow, USSR, 27 - 31 May1991*, edited by M. Man’ko. Commack, NY: Nova Science Publishers, 1991.

381. Dowling, Jonathan P., Wolfgang P. Schleich, and John A. Wheeler. “Interference in Phase Space.” *Annalen der Physik* 7, No. 48 (1991): 423 – 502.

382. Wheeler, John Archibald. “How Come Existence?” In *Science et Sagesse: Entretiens de l'Académie Internationale de Philosophie des Sciences, 1990 [Science and Wisdom: Meeting of the International Academy of Philosophy of Science, 1990]*, edited by Evandro Agazzi; Académie Internationale de Philosophie des Sciences. Fribourg, Suisse: Éditions Universitaires, 1991, 155 - 160.

383. Wheeler, John Archibald. “Albert Einstein.” In *The World Treasury of Physics, Astronomy, and Mathematics*, edited by Timothy Ferris. Boston: Little Brown & Co., 1991, 563 – 576.

384. Wheeler, John Archibald. “Reflections on the Mystery of the Missing Mass.” *The Observatory* 111, (1991): 53 – 55; invited report, Royal Astronomical Society, London, UK, 12 October 1990.

385. Taylor, Edwin F., and John Archibald Wheeler. *Spacetime Physics* (2nd edition). New York: W.H. Freeman, 1991.

386. Wheeler, John Archibald. “Recent Thinking about the Nature of the Physical World: It from Bit.” in *Frontiers in Cosmic Physics: Symposium in Memory of Serge Alexander Korff,* edited by Rosalind B. Mendell and Allen I. Mincer. New York: The New York Academy of Sciences 655 (1992): 349 – 364.

387. Wheeler, John Archibald. [Vignettes], 84 – 86, 94, 125 – 126, 143 – 145, 174 – 175, 179, in *A Brief History of Time: A Reader’s Companion*, edited by Stephen Hawking. New York: Bantam Books, 1992.

388. Wheeler, John Archibald. “Toward a Thesis Topic.” In *Directions in General Relativity: Proceedings of the 1993 International Symposium on Directions in General Relativity, University of Maryland, College Park, May 27-29, 1993, Vol. 1. Papers in Honor of* ***Charles Misner****,* edited by B.L. Hu, M.P. Ryan, and C.V. Vishveshwara. New York: Cambridge University Press, 1993, 397 – 401.

389. Wheeler, John Archibald. “The Young Feynman.” In *“Most of the Good Stuff:” Memories of Richard Feynman.* Edited by Laurie M. Brown and John S. Rigden. New York: American Institute of Physics, 1993, 19-32.

390. **Holz, Daniel E**., **Warner A. Miller**, **Masami Wakano**, and John Archibald Wheeler. “Coalescence of Primal Gravity Waves to Make Cosmological Mass without Matter.” In *Directions in General Relativity: Proceedings of the 1993 International Symposium on Directions in General Relativity, University of Maryland, College Park, May 27-29, 1993,Vol. 2. Papers in honor of* ***Dieter Brill***, edited by **B.L. Hu** and T.A. Jacobson. New York: Cambridge University Press, 1993, 339 – 359.

391. Ciufolini, Ignazio[489], and John Archibald Wheeler, *Gravitation and Inertia*. Princeton, NJ: Princeton University Press, 1995.

392. Wheeler, John Archibald and **Kenneth Ford**. *Geons, Black Holes, and Quantum Foam: A Life in Physics*. New York: W. W. Norton, 1998.

393. Wheeler, John A. “Wheeler’s Rules of Writing.” *American Journal of Physics* 67, No. 11 (Nov 1999): 945 – 946.

394. Tegmark, Max, and John Archibald Wheeler. “100 Years of Quantum Mysteries.” *Scientific American* 284, No 2 (Feb 2001): 68 – 75.

395. Cirone, M. A., K. Rzążewski, W. P. Schliech, F. Straub, and J. A. Wheeler. “Quantum Anticentrifugal Force.” *Physical Review A* 65 (21 Dec 2001): 022101-1 – 022101-6.

396. **Holz, Daniel E.,** and John A. Wheeler. “Retro-MACHOs: π in the Sky?” *The Astrophysical Journal* 578 No. 1 (10 Oct 2002): 330 – 334.

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